TONAL INDUCTION OF SHORT DURATION TINNITUS

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ABSTRACT

The present study, comprising two series of experiments, was concerned with the tonal induction of tinnitus in seven subjects (10 ears). Four subjects (six ears) participated in the first series, which comprised the presentation of a 1000 Hz tone at 80, 85, 90 and 95 dB SPL for 1, 3 or 5 minutes; at 100 dB SPL for 1 or 3 minutes, and at 105 dB SPL for one minute. In the second series five subjects (7 ears) were presented with inducing stimuli of 500, 1000, 2000, 3000 and 4000 Hz, at a fixed intensity (90 dB SPL) for a fixed duration (3 minutes). For both series, following the presentation of the tone, the subjects performed a dichotic loudness matching task, with white noise administered to the non-stimulated ear.

All subjects reported hearing a rushing noise tinnitus following the tonal stimulation; this tinnitus ended abruptly after 80-85 seconds, on average, instead of gradually decaying. As the level of the inducing tone was raised the loudness of the induced tinnitus increased from around 4 dB SL for the 80, 85 and 90 dB SPL conditions to 10-15 dB SL for the 95, 100 and 105 dB SPL conditions. The reported loudness of the induced tinnitus ranged from -4.5 dB SL to 24.5 dB SL, with an average of 7.8 dB SL. Considerable variation in loudness was apparent

between different subjects and between different ears of the same subject.

Consequently it would appear that tonally induced tinnitus behaves in a similar manner to pathological tinnitus.

CHAPTER I

INTRODUCTION

To begin with a discussion on tinnitus is presented, what it is and how it affects people. Secondly, a brief treatment of temporary threshold shift, or auditory fatigue, is offered because there is a close relationship with tinnitus - so close in fact that they generally occur together and consequently much of the literature concerning fatigue is pertinent to tinnitus. The final section of the introduction, on noise-induced tinnitus, is included because it is directly related to this study.

Tinnitus

The term 'tinnitus' is defined as an "illusory sensation of sound not brought about by simultaneously applied acoustical or vibration signals. Often referred to as 'noises in the head', 'ringing in the ears' etc". (Lutman and Haggard, 1983, p.334).

Tinnitus can be classified as being one of two types: One is objective tinnitus, in which sounds can be perceived emanating from a person's ear. Zurek (1981), employing a probe microphone in the ear canal detected oto-acoustical emissions from 22 ears of 16 people. Generally in these cases the person is unaware of the condition, although in extreme cases these sounds can be heard by people without aids (Glanville and Coles, 1971). Hence, objective tinnitus cannot be regarded as true tinnitus.

There have been many different postulates as to the cause of the problem. Some of these include vascular abnormalities, tics of intratympanic muscles (Parkin, 1973), and vibrations in the cochlea (Kemp 1979; Wilson, 1980).

The second type of tinnitus is subjective tinnitus, perceived only by the person concerned. This is the type which will concern the rest of this discussion. This is the common form; nearly all normal listeners experience what Hazell (1979) terms "transitory unilateral tonal tinnitus." (p.468).

Tinnitus is, generally speaking, only brought to a specialist's attention when it becomes a severe problem for the sufferer, or when it is associated with hearing loss. Estimates of the prevalence of tinnitus, in people with hearing loss, range from 33.3 per cent (Hazell, 1979) to 85 per cent (Fowler, 1944), with most studies showing a peak in the 50-60 age group (Hazell, 1979).

Reported characteristics of tinnitus vary from person to person depending upon their vocabulary and powers of description, for example: hissing, roaring, ringing, whistle, tone, hum, crickets and frogs croaking.

The intensity of the tinnitus is typically between 5 and 10 dB SL (Penner 1983a); that is, 5 to 10 dB above the sufferer's threshold of hearing. This low sensation level makes it difficult for the non-sufferer to comprehend the degree of annoyance suffered by the person with tinnitus. McFadden and Wightman (1983) liken this to the buzzing of an insect in a room, or the handling of cellophane wrappers in a quiet cinema theatre. The sound is not particularly loud but is very annoying, and for the tinnitus sufferers this annoyance is continuous. Lack of comprehension on the part of the non-sufferer, coupled with an inability to describe what living with tinnitus is like, was found to be one of the most important problems concerning tinnitus sufferers, in a survey undertaken by Tyler and Baker (1983). Their study reported a wide diversity of problems, with for example, watching television, listening to music, getting to sleep, headaches and confusion.

In order to obtain an accurate match to a person's tinnitus, Hazell (1981) employed a music synthesizer. This involved several hours of interacting with the tinnitus sufferer. Hazell's results show that what had previously been thought of as a simple stimulus was, in fact, complex - being made up of a large number of different sounds, "a common combination is a sine wave centred in a rather quieter narrow band of white noise" (Hazell, 1981, p.190).

One positive effect of the matching was that the patient could use a copy as a basis for discussion with others.

The pitch of the tinnitus displays a diverse range, from the low rumbling sounds found in Meniere's Disease, to a high pitch of around 10,000 Hz found by Young and Lowry (1981, 1983). Consequently, an accurate profile of an individual's tinnitus is of considerable advantage to the clinician for treatment purposes. This is especially so with regard to the use of masking instruments. If a person has a narrow-band tinnitus, then being able to determine the extent of the problem means that the masker can be 'tailor made' for the individual, and as a result will produce less hearing loss in the unaffected regions (Penner 1983b).

Another form of treatment requiring an accurate profile of a person's tinnitus was attempted by Young and Lowry (1981, 1983) using intense sound. The rationale behind their approach was: "Might exposure to a narrow-band or tonal stimulus of high intensity be capable of 'burning out' a tinnitus-producing spectral region?" (McFadden, 1982, p.58). They attempted to eliminate the monaural tinnitus suffered by one of the authors. He was exposed to a steady tone of 2000 Hz at 107 dB SPL for 10 minutes, which resulted in permanent tinnitus in both ears. This was followed, three months later, by a monaural exposure of 500 Hz at 121 dB SPL for 21 minutes resulting in a reduction in tinnitus pitch in both ears. Over the course of weeks, the tinnitus returned to its original frequency, but with different recovery rates in the two ears.

Temporary Threshold Shift

Discussion of temporary threshold shift (TTS) or auditory fatigue, is warranted at this stage, since it is intimately associated with tinnitus. Threshold shift results from over stimulation of the hair cells of the inner ear by an intense noise resulting in decreased hearing sensitivity (Gelfand, 1981). If the threshold returns to normal levels, it is referred to as a temporary threshold shift, but if it remains at some level above normal, for a particular individual, then it is a permanent threshold shift. In this case, hearing loss has occurred.

The duration of the threshold shift depends upon five factors: "(1) The time between the cessation of the fatiguing stimulus and the post-exposure threshold determination - called the recovery interval; (2) The intensity of the fatiguing stimulus; (3) The duration of the fatiguing stimulus; (4) The frequency of the fatiguing stimulus; and (5) The frequency of the test stimulus". (Moore, 1982, p.63).

The longer the recovery interval, the smaller the threshold shift becomes, although recovery from a large threshold particularly at high frequencies is followed by a 'bounce' immediately following exposure. Sometimes the initial threshold level is overshot during the recovery period, resulting in temporary sensitization (Hughes and Rosenblith, 1957).

As the intensity of the fatiguing stimulus increases so does the threshold shift. The frequency range over which the threshold shift occurs becomes wider as the stimulus level is raised, and the effect is asymmetric in that the 2000-6000 Hz range is most severely affected (Katz, 1978, p.63). For fatiguing intensities of 90-100 dB the threshold rises dramatically. This point of inflection has been proposed as the division "between fatigue which is physiological and transient in nature and fatigue which is more permanent and pathological in nature." (Moore, 1982, p.64). For a given intensity the amount of threshold shift will increase with duration; the rate at which the threshold increases is proportional to the log of the exposure time. At low frequencies, particularly when the fatiguing stimulus is noise, or a rapidly interrupted tone, the growth rate is reduced.

Noise-Induced Tinnitus

There are several ways to induce tinnitus in normal hearing ears. These methods involve either administration of certain drugs (for example, salicylates, caffeine), or exposure to intense sound under controlled conditions.

One reason for inducing tinnitus in normal hearing subjects is to gain an understanding of people suffering pathological tinnitus. Few studies, to date, have employed sound to induce tinnitus.

An early study involving noise-induced tinnitus is that of Ewing and Littler (1935), who investigated auditory fatigue and adaptation. They reported that all subjects experienced a rushing noise, usually lasting about two minutes, immediately after being exposed to 500 Hz at 100 dB SPL for three minutes.

Hirsh and Ward (1952) report that tinnitus induced by a 500 Hz tone at 120 dB for three minutes sounded like an "unusually loud roaring noise" (p.135)which weakened and died out at about 70 or 80 seconds.

Loeb and Smith (1967) investigated "the relationship of the characteristics of the induced tinnitus and those of the inducing stimuli and of the temporary threshold shift" (p.453). They employed eight stimuli for the induction of tinnitus - a 300 Hz tone, a 500 Hz tone, a 1000 Hz tone, a 2000 Hz tone, a white noise, a 600-1200 Hz noise, a 1200-2400 Hz noise, and a 2400-4800 Hz noise. The test stimuli were pulsed with an initial exposure of 90 dB for five minutes. Each subject was exposed repeatedly until a temporary threshold shift of 40 dB had been attained, or the inducing stimuli reached 120 dB. When the inducing stimulus was terminated the subject was asked if there was any sound in his ears or head, and if so, to describe it. He then manipulated an oscillator to match the pitch of the sound he heard. Subjects reported that the resulting tinnitus was generally tonal rather than 'noisy' and that the pitch of the tinnitus increased with the frequency of the inducing stimulus, with considerable individual differences. There was no mention of the loudness or duration of the tinnitus.

Atherley et al (1968) studied the relationship between noise-induced short duration tinnitus and auditory fatigue. Their inducing stimuli comprised "a white noise source presented to the subjects in one-third octave bandwidths centred at either 2, 3, 4 or 6 KHz", (p.1503) at 110 dB SPL for 5 minutes to one ear. Immediately following exposure to the inducing stimulus, a comparison tone was presented to the non-stimulated ear and adjusted by the experimenter until the subject reported that it matched his tinnitus for both frequency and level. The levels of tinnitus were reported in sensation levels and found to be non-significant, although in agreement with other studies reporting that most tinnitus is reported at levels below 10 dB SL. Atherley et al (1968) also found that the relationship between the induced tinnitus and the maximum threshold shift was such that the pitch of one and the frequency of the other were both related to the centre frequency of the one-third octave stimulus.

One major criticism of these experiments regards the levels of the inducing tone. The intensities of the inducing stimuli were in the vicinity of 110-120 dB SPL for up to five minutes. Such levels of inducing stimuli would have resulted in the stimuli becoming distorted, particularly at the higher frequencies, thus stimulating more of the cochlea than aimed at. In addition, such large intensities might not only have induced tinnitus, but also a permanent threshold shift.

The method of recording the tinnitus and threshold shift adopted by Loeb and Smith (1967) seems inferior to that of Atherley et al (1968). When recording the induced tinnitus the subject was first asked if he noticed any sound in his ears or head, and then to describe it. The comparison tone was not presented to the non-stimulated ear until 90 seconds after exposure to the inducing stimulus had ceased. It will be remembered, from the above discussion of temporary threshold shift, that the longer the delay between the fatiguing stimulus and the testing stimulus the weaker the threshold shift becomes. In addition, the pulsating inducing stimulus has less effect than a steady presentation (Gelfand, 1981).

The study of Loeb and Smith (1967) however was superior in one respect, to the study of Atherley et al (1968). Atherley et al (1968) had the experimenter adjust the frequency and level of the comparison tone according to the subject's instructions, rather than the subject adjusting it. Having the subject manipulate the comparison tone makes for more accurate results, as the subject's concentration is not affected by instructing the experimenter how to adjust the comparison tone. By adjusting the comparison tone himself, the subject is able to concentrate solely on comparing the two.

With these criticisms in mind, the present study investigated the effects of using relatively low levels of inducing stimuli. Since the recording of tinnitus pitch is a complicated procedure (Hazell, 1979), it was decided to investigate how the level of tinnitus changed over time, with respect to the inducing stimuli. Consequently a white noise rather than a tone was presented to the non-stimulated ear immediately following termination of the inducing stimulus. The level of the white noise was manipulated by the subject to match the loudness of the induced tinnitus in the fatigued ear (a dichotic loudness matching task).

CHAPTER II

AIMS OF THE STUDY

The aims of the experiments that follow are to investigate whether; (1) the level of the inducing tone effects (a) the loudness, and (b) the duration of the induced tinnitus; (2) the period of exposure to the inducing tone affects (a) the loudness, and (b) the duration of the induced tinnitus; and (3) the frequency of the inducing tone affects (a) the loudness, and (b) the duration of the induced tinnitus.

Associated with these aims is an interest in how the level of the induced tinnitus changes with time.

CHAPTER III

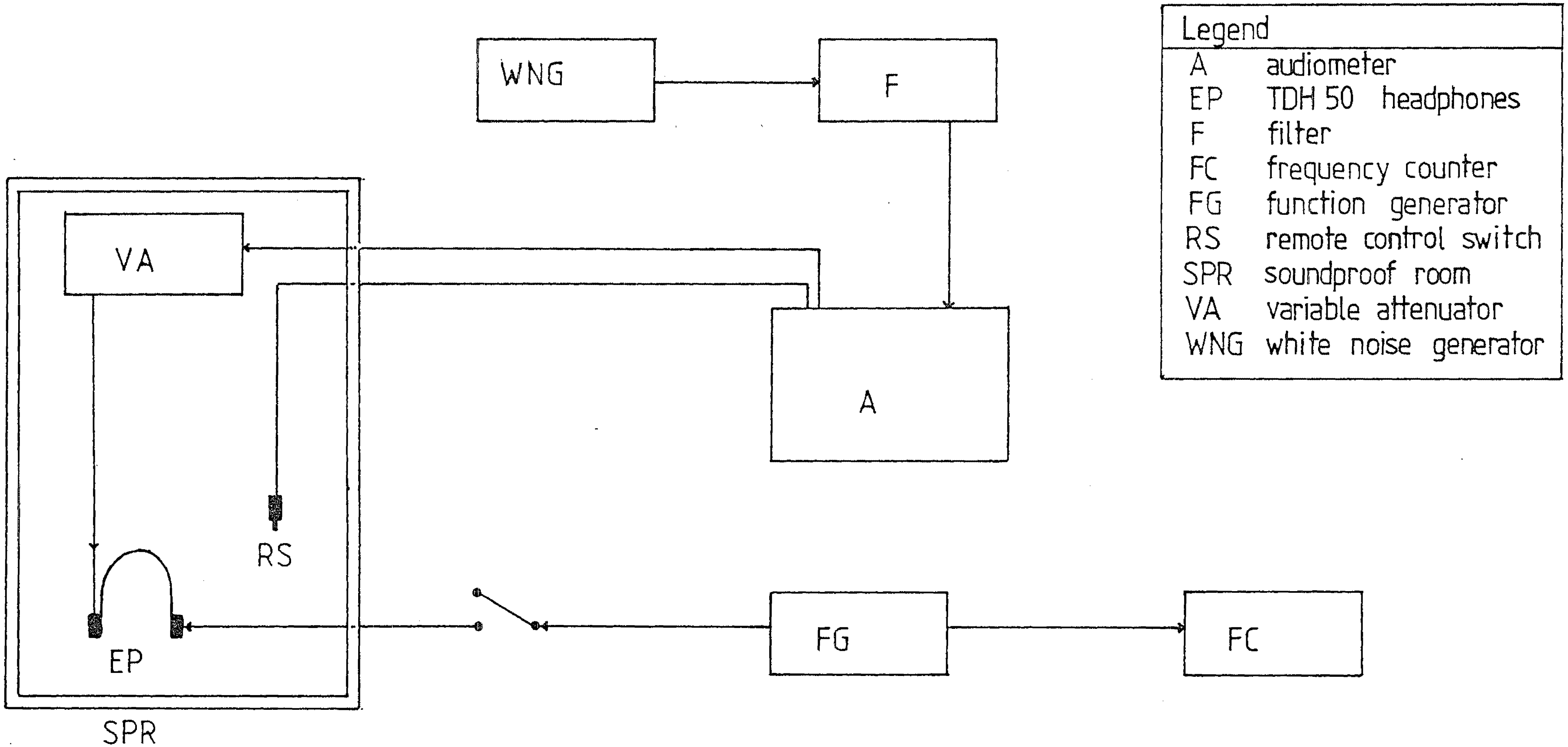
METHOD

APPARATUS

An initial hearing test, used for screening the subjects, was conducted using a 1703B Grason Stadler Recording Audiometer. This initial hearing test was conducted with the subject seated inside a sound attenuating chamber while the experimenter and audiometer remained outside.

In the experiment proper, the inducing tone was produced by an Interstate Electronics Corporation (IEC) function generator (Model F55A). A TRIO frequency counter was employed to measure the frequency of the tone. The tone was fed to one side of a set of TDH50 headphones, via a manual switch.

White noise was produced by a Lafayette noise generator connected to a low-pass filter (Butterworth, fc = 7000Hz), which fed into the attenuator of the Grason Stadler recording audiometer. The output of the audiometer was further attenuated (Marconi, model TF338C), and finally fed into the other TDH50 earphone. See Figure 1 for a schematic layout of the equipment.


WNG
F
VA
A
RS
EP
SPR
FG
FC
Legend
A audiometer
EP TDH 50 headphones
F filter
FC frequency counter
FG function generator
RS remote control switch
SPR soundproof room
VA variable attenuator
WNG white noise generator

The level of white noise could be controlled by the subject using the remote control trigger mechanism of the audiometer. The level of the noise was traced by the audiometer chart recorder.

When used in its proper capacity the audiometer presented one frequency, to the person being tested, for 30 seconds before the next was presented. Time periods of up to four minutes could be charted.

The levels of white noise and tone were calibrated using a voltmeter (Bruel and Kjoer, Type 2409).

An oscilloscope was employed to check the flow of tone or noise from one component to the next.

SUBJECTS

Seven subjects (10 ears) ranging in age from 20 to 32 years (average 23) served in the experiment; five male and two female. Tinnitus was induced in both ears of three subjects at different times and in only one ear of the remaining four subjects.

For analysis each ear is considered individually. Ears 1 and 2 belong to Subject 1; Ears 3 and 4 to Subject 2; Ear 5 to Subject 3; Ear 6 to Subject 4; Ears 7 and 8 to Subject 5; Ear 9 to Subject 6; and Ear 10 to Subject 7.

Ears 1, 2, 3, 4, 5 and 6 participated in the first experiment, investigating the effects of loudness and duration of the inducing tone on the resulting tinnitus. Ears 1, 2, 6, 7, 8, 9 and 10 participated in the second experiment, investigating the effects inducing tones of different frequencies had on the induced tinnitus.

All subjects had hearing levels between -10dB and +20dB, being considered normal hearing (Lutman, 1983), at the frequencies being tested. None reported suffering from tinnitus.

PROCEDURE

All subjects underwent a preliminary hearing test prior to the experiment proper. This was accomplished using the 1703B Grason Stadler Recording Audiometer, which provided fixed-frequency pure-tone signal presentations and automatic recording of responses made by the person being tested. The test comprised seven tones in succession, first to the left ear, then to the right. Total testing of both ears required 7.5 minutes.

The experiment proper comprised two parts. The first investigated the effects of the level and duration of the inducing tone on the resultant tinnitus, while the second was concerned with the effects of varying the frequency of the inducing tone on the induced tinnitus. All subjects underwent a minimum of two trials, and a maximum of three, for each condition.

Upon termination of the inducing tone, the subject's task was to match the loudness of white noise, presented to the contralateral ear, with the loudness of the induced tinnitus - a dichotic loudness matching task - for the duration of the tinnitus. Thus a tracing of the white noise, representing the induced tinnitus present in the stimulated ear, over time, was obtained, giving an indication of the levels of the tinnitus reached and its duration. The dichotic loudness matching task involved the subject constantly manipulating the remote control trigger mechanism.

In both parts of the experiment, the inducing tone was switched on prior to the subject putting the headphones on to prevent damage from impulsive tones.

Part 1 of the present study involved presenting a 1000 Hz tone to one ear for a predetermined period of time at different levels. The intensity of the inducing tone ranged from 80 dB SPL to 105 dB SPL, in 5 dB increments. The period of exposure to the inducing tone comprised 1, 3 and 5 minutes for all levels except 100 dB (1 minute and 3 minute exposures) and 105 dB (1 minute exposures). Immediately the tone was terminated, white noise was presented to the subject's contralateral ear.

In the second part of the experiment the frequency of the inducing tone was varied while maintaining a fixed duration of 3 minutes and a level of 90 dB SPL.

The frequencies of the inducing tone were 500, 1000, 2000, 3000 and 4000 Hz.

The order determining which ear was exposed to the inducing tone was not fixed initially. However, due to time constraints it was decided to complete a set of trials for one ear before starting the next. Hence some subjects, notably Subjects 3 and 4, completed all trials for one ear (Ears 5 and 6 respectively) while only partially completing the set of trials for their other ear. The partially completed trials are not included, as they were not able to be utilized in the data analysis.

Subjects were also administered five threshold tests per ear, for the white noise. These were presented on different, not necessarily consecutive, days. Subjects were instructed to press the trigger when they heard the noise and to release it when the noise became inaudible, but not to let it grow too loud nor to remain inaudible for too long. Five trials were presented in an attempt to eliminate any daily fluctuations, and thus provide an accurate threshold estimate. The threshold of white noise was used for converting sound pressure levels (SPL) to sensation levels (SL).

Each subject underwent, at most, two trials per day, with at least four hours between trials.

In order to complete all sets of trials, in the first part of the experiment, for both ears, between 60 and 90 trials (taking 164 and 246 minutes respectively) per condition were required, depending on whether two or three trials were conducted. The maximum number of trials was not reached, as only a few conditions necessitated three trials. The second part of the experiment required between 20 and 30 trials (60 and 90 minutes respectively), again depending on whether two or three trials per condition were required. Again the maximum number of trials was not reached.

CHAPTER IV

RESULTS

The results show considerable variation both between subjects and between different ears of the same subjects. Consequently it was decided to treat all ears individually, rather than making left and right distinctions.

Figure 2 shows a typical result from one trial, in this case the first trial for Ear 1 (Subject 1) following stimulation by a 90 dB·SPL, 1000 Hz tone for one minute. The audiometer chart employed was originally graduated in 30 second intervals, where frequency changes would normally have occurred. For ease of transferring results, the 30-second intervals were divided into 15 second intervals, termed epochs. Each epoch was allocated a number; 1, 2, 3, 4 .... Thus four epochs equal one minute.

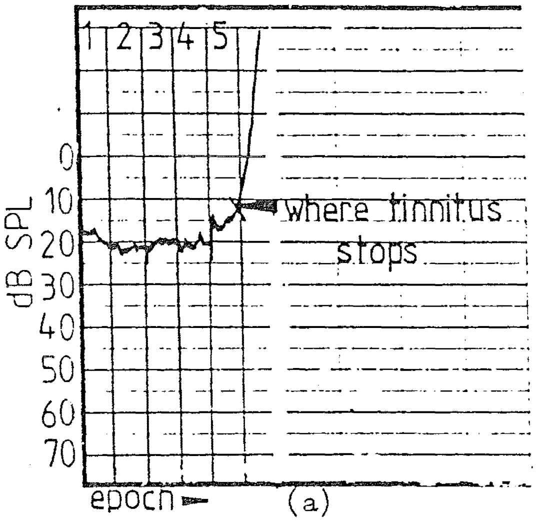
The logic of this experiment assumes that the contralaterally presented white noise was matched to the loudness of the induced tinnitus. In this section, the level of this white noise is referred to, for brevity, as the loudness of the tinnitus.

From Figure 2 it can be seen that the white noise, judged as loud as the tinnitus, grows to just

NAME S1 E1

90dB/1min/1000Hz (dB-20)

Trial 1



(a)

epoch no.	$\bar{x}$ value
1	19
2	21
3	20
4	20
5	16

(b)

$$\text{duration} = d(\text{mm}) \times 2{\cdot}5$$
$$= 28 \times 2{\cdot}5$$
$$= 70\text{sec.}$$

(c)

under 20 dB SPL and fluctuates about this level until the end of the fourth epoch, where it begins to decay. It reaches a lowered level (16 dB SPL) and then decays very rapidly. This precipitous termination of tinnitus was a commonly reported characteristic.

The average SPL of the noise was measured for each epoch and recorded to give a measure of how the tinnitus changed over time. This method of data collection was used for all trials. Upon completion of all trials in a particular condition, an average value for each epoch was obtained and plotted.

The total duration of the tinnitus was estimated as the record length to the beginning of the final upward movement of the recording pen. This method of duration estimation produced slightly shorter durations than are shown in Figures 3, 4, 6, and 7, and the individual results in the Appendices. This is because the tinnitus frequently stopped while the recording pen was part-way through an epoch. When determining the average loudness of an epoch, in such cases, however, the epoch was treated as complete. Consequently, Figures 3, etc., tend to present a slight exaggeration of duration.

NOISE THRESHOLDS

Table 1 shows thresholds for the white noise for each ear. Note that there is considerable variation

ear	threshold
1	16•5
2	22•6
3	3•7
4	8•5
5	15•5
6	10•4
7	9•5
8	12•9
9	18•8
10	16•5

[values in dBSPL]

Table 1: Average white noise thresholds for each ear. Thresholds range from 3.7 dB to 22.6 dB SPL, with an average of 13.5 dB SPL. Note the large variations between individual ears of different subjects, and the same subject.

between the different ears, ranging from 3.7 to 22.6 dB SPL, with an average of 13.5 dB SPL.

SUBJECTIVE REPORTS OF INDUCED TINNITUS

In all cases, subjects reported the induced tinnitus as sounding "noisy", with an occasional tonal component. This 'rushing' tinnitus lasted 80-85 seconds on average, although there was considerable individual variation. A second feature common to all subjects was that the tinnitus was judged to cease abruptly rather than decaying gradually.

At the higher intensities (100 and 105 dB SPL) in Part One of the present study, subjects reported a brief period (10-15 seconds) of silence upon termination of the inducing tone, followed by a rapid growth of tinnitus prior to a plateau stage being reached.

One subject in the second part of the study, reported a difference in tinnitus pitch associated with the frequency of the inducing tone. This involved a reported low rumbling sounding tinnitus for the 500Hz condition. This observation was not reported in any other condition by this or any other subject.

PART 1: EFFECT OF LEVEL AND DURATION OF THE INDUCING TONE

This experiment involved four subjects (6 ears). Discussion of the results will be divided into two parts: (1) loudness of the induced tinnitus; and (2) the duration of the induced tinnitus.

(1) Loudness of the Induced Tinnitus

Table 2 shows the peak loudness of the tinnitus in Sensation Level (SL). This was the loudest (i.e. maximum sensation level of the contralateral white noise) attained when the values for each epoch were averaged over trials for a particular condition. The use of sensation level makes comparisons between different ears easier than if Sound Pressure Level (SPL) was used, since there were large differences in the noise thresholds. Table 2 shows that the tinnitus ranged in loudness from -1 dB SL to 24.5 dB SL, with 67 per cent below 10 dB SL, 30.5 per cent between 10 dB SL and 20 dB SL, and 2.5 per cent above 20 dB SL.

Figure 3 shows the results averaged across all ears. The Figure shows the maximum loudness reached, the duration of the tinnitus, and how the tinnitus changes over time for each of the three durations (1, 3 and 5 minutes) of inducing tone. Results for individual ears appear in Appendix 1.

1min

dB	Ear 1	Ear 2	Ear 3	Ear 4	Ear 5	Ear 6
80	1	1	11	9	7•5	8•5
85	6	-1	5	11•5	6•5	7•5
90	5	6	8	17•5	10•5	3
95	7•5	10•5	10	18	10•5	15•5
100	9•5	7	14	24•5	13•5	5
105	11	7	19	24	12•5	

3min

80	3•5	4•5	3	10	11	11
85	0	1	8	13•5	12•5	8•5
90	6	6	12•5	3	8	7
95	5	6	10	21	9•5	11•5
100	6•5	8•5	18	17	9•5	5•5

5min

80	11•5	3	1	8•5	9•5	7•5
85	2•5	3	8	11•5	9•5	6
90	0•5	7•5	5	13	6•5	4•5
95	6•5	4•5	10	19	11•5	7•5

[values are dBSL]

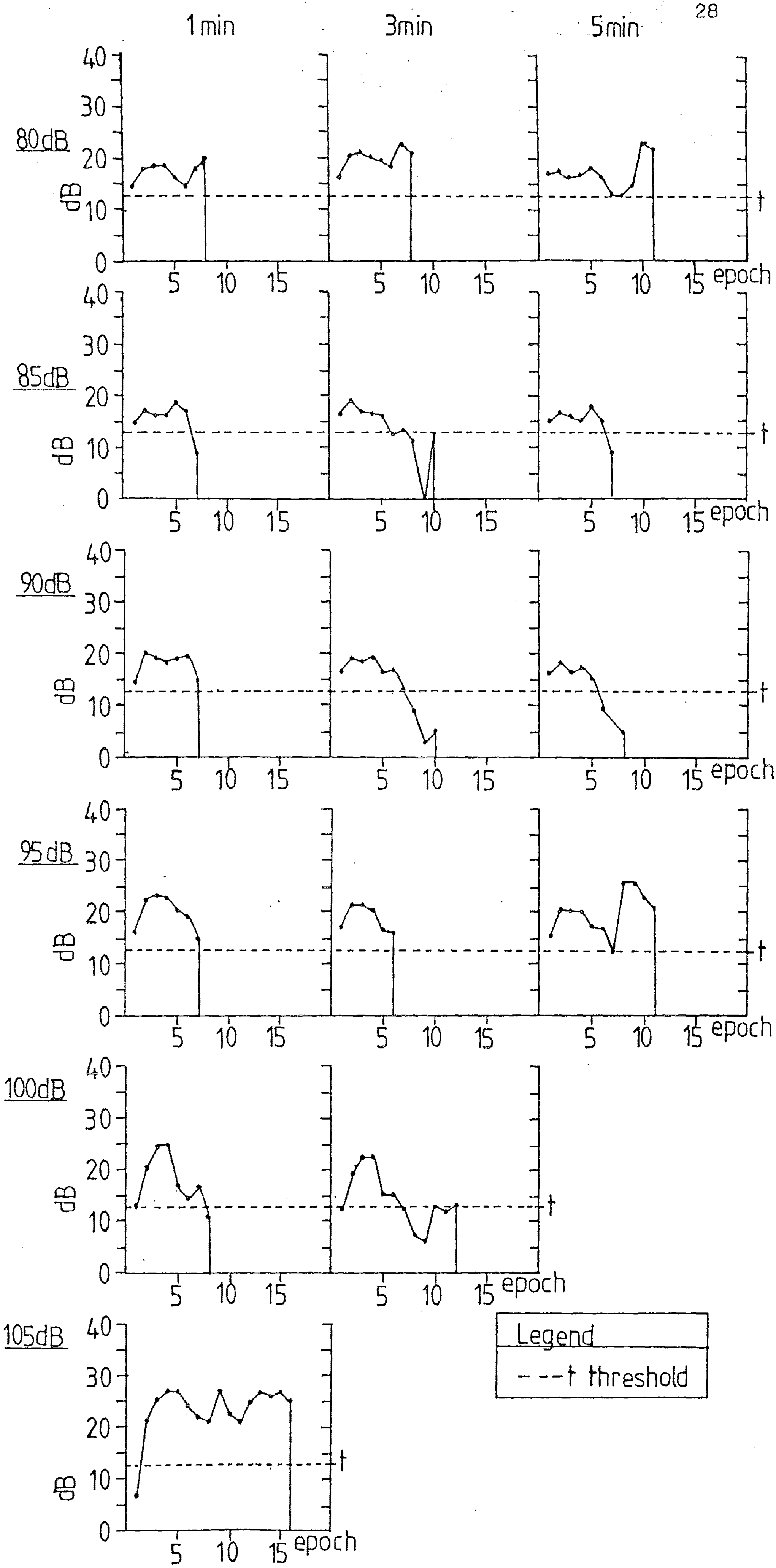
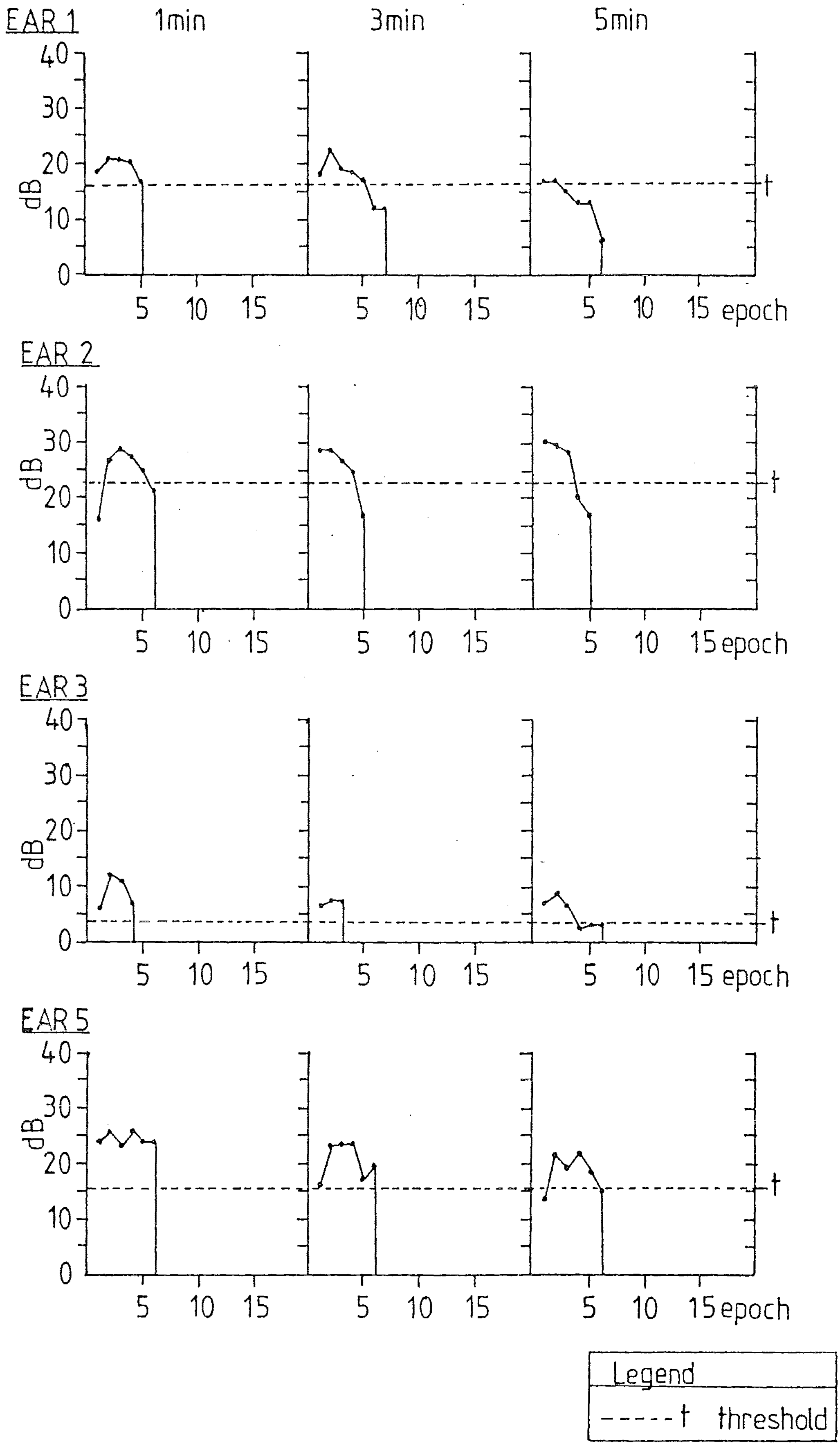

1 min
3 min
5 min
80dB
85dB
90dB
95dB
100dB
105dB
dB
epoch
Legend
---† threshold

Figure 3 shows that the tinnitus began with an initial period of build up in loudness. Thus the tinnitus did not reach its maximum loudness immediately the tone was terminated. This effect was most pronounced for the higher levels (100 and 105 dB SPL) of the inducing tone.

It can also be seen, more particularly at the higher intensities, that as the level of the inducing stimulus increased so did the loudness of the resulting tinnitus. This becomes noticeable in the 95 dB condition. In the 80, 85 and 90 dB conditions the induced tinnitus fluctuates around 20 dB SPL (6-8 dB SL) before ceasing. The tinnitus was louder in the 95-105 dB conditions, reaching 20-30 dB SPL (6-16 dB SL).

Subjects reported having difficulty discerning the tinnitus induced in the 80 dB condition. Figure 3 shows the tinnitus induced by this to have been weak; subjects also reported difficulty in distinguishing between the sound of the tinnitus and other extraneous sounds, such as heart beat and other body noises. Consequently considerable concentration was required to monitor the tinnitus. Momentary loss of concentration may have influenced the results.

Figure 4 shows individual results from four ears for the 90 dB condition. One of the first things to be


EAR 1
1min
3min
5min
40
30
20
10
0
dB
5 10 15
5 10 15
5 10 15 epoch
EAR 2
EAR 3
EAR 5
Legend
- - - - - † threshold

noted is the difference in thresholds (mentioned above). Thus it can be seen that, when discussing the loudness of the tinnitus, sound pressure level is not particularly meaningful while sensation level makes comparisons easier. From the one minute condition it can be seen that the tinnitus reaches 20 dB SPL for Ear 1 (Subject 1) and 12 dB SPL for Ear 3 (Subject 2). When sensation levels are used these values are reduced to 4 dB SL and 0.8 dB SL, respectively, indicating that for this example, Subject 2 (Ear 3) reported a louder tinnitus than Subject 1 (Ear 1) despite Subject 1 (Ear 1) producing larger sound pressure levels. Also the results are much more similar.

Another point of interest is the differences in tinnitus recorded both between ears of different subjects and ears of the same subject. This suggests that the results obtained are dependant upon the individual ear as much as or more than on characteristics of the inducing tone.

Increasing the duration of exposure to the inducing tone beyond one minute did not produce any marked effect on loudness of the tinnitus.

Results were analysed using one-way analyses of variance (ANOVA) for each duration of the inducing tone using the BMD2PV package.

Ears rather than subjects were chosen as the random factor. One-way analyses of variance were employed because the 105 dB condition was not presented for three or five minutes; neither was the 100 dB condition for the 5 minute condition. Note also that one subject was not presented the 105 dB condition at all.

A significant effect of level on tinnitus loudness was found for the one minute condition ($F(5,20)=4.95$, $p<0.05$), but not for the three minute condition ($F(4,20)=1.39, p>0.05$), or the five minute condition ($F(3,15)=2.37, p>0.05$).

A two-way analyses of variance was also conducted, using three durations (1, 3 and 5 minutes) and four levels of the inducing tone (80, 85, 90 and 95 dB SPL) to determine whether the loudness of the induced tinnitus was dependent upon the duration of exposure to the inducing tone. It was found that the loudness of the tinnitus was dependent upon the level of the inducing tone ($F(3,15)=4.53, p<0.05$); the duration of exposure to the inducing tone had no effect on the loudness of the tinnitus ($F2,10)=1.31, p>0.05$); and the interaction effect was not significant ($F(6,30)=0.64, p>0.05$).

(2) Duration of the Induced Tinnitus

Table 3 presents the average duration of the tinnitus for each ear for each condition. This table shows the duration of the tinnitus (for the definition of this see above) averaged over the number of trials for a particular condition. Upon looking at this table it can be seen that there is a considerable degree of variability between and within ears. This was a surprising and consequently interesting finding as it was expected that by increasing the level and period of exposure to the inducing tone, the durations of the tinnitus would also increase.

Figure 5 shows the median and quartile durations of the tinnitus. Median measures were used because the large variability in individual results produced a skewed distribution. The quartile ranges illustrate the substantial overlapping which occurred between conditions. It appears that the five minute conditions produce the greatest ranges in variability of durations. This is particularly so in the 80 dB condition.

Looking at Figure 5, an obvious effect is that neither the level nor the duration, of the inducing tone, produces any noticeable effect on the duration of the tinnitus.

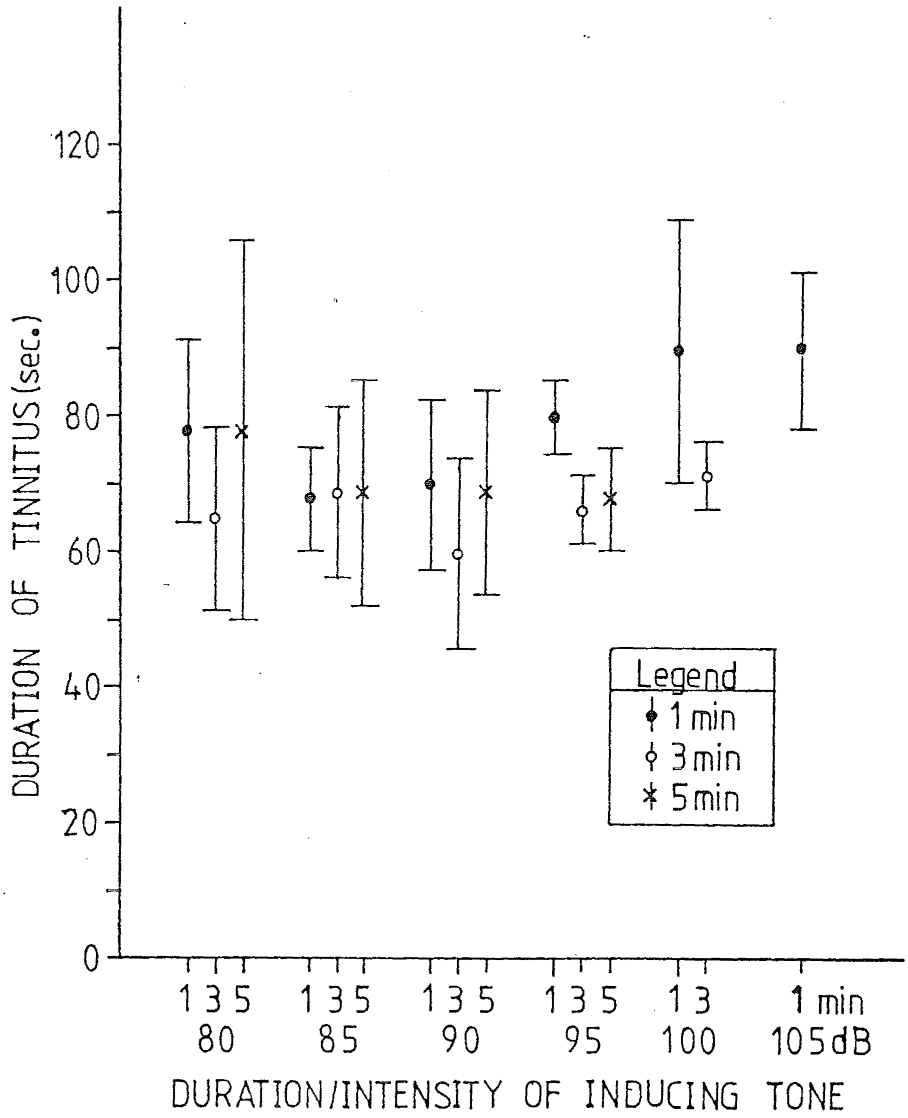
	dB	Ear 1	Ear 2	Ear 3	Ear 4	Ear 5	Ear 6
1min	80	83	76•5	50	77•5	105	76•5
	85	75	73	57•5	69	96•5	54
	90	67•5	84	56•5	75	79	70
	95	79	82•5	74	72•5	89	63
	100	80•5	92•5	86•5	115	92•5	66•5
	105	82•5	83	91•5	231•5	90	-

3min	80	79	73	22•5	57•5	84	80
	85	80	62•5	76•5	127•5	72•5	54
	90	75	63	19	85•3	81•5	81•5
	95	57•5	70•5	63	65	72•5	66•5
	100	67•5	77•6	62•5	174	62•5	55

5min	80	91•5	66•5	41•5	114	120•5	55
	85	65•5	79	49	67•5	72•5	91•5
	90	84	65	66	60	82•5	51•5
	95	66•5	75•5	50	116•5	65•5	67•5

[values in sec.]

Table 3: Duration of the tinnitus (seconds) for each subject at each level of the inducing tone. Separate blocks are used for the different periods of exposure to the inducing tone (1, 3 and 5 minutes) Durations range from 50 to 231.5 seconds for the 1 minute condition; from 19 to 174 seconds for the 3 minute condition; from 41.5 to 120.5 seconds for the 5 minute condition.



DURATION OF TINNITUS (sec.)
0
20
40
60
80
100
120
1 3 5
80
1 3 5
85
1 3 5
90
1 3 5
95
1 3
100
1 min
105dB
DURATION/INTENSITY OF INDUCING TONE
Legend
1 min
3 min
5 min

Another feature of Figure 5, worthy of note, is that the range of durations for the three minute and five minute conditions tend to decrease as the level of the inducing tone was increased. This could have been due to an increased exposure having been required to establish a stable tinnitus pattern. A greater range of durations was obtained for the one minute conditions, perhaps because the shorter exposures were insufficient to establish a stable pattern of tinnitus.

. One-way analyses of variance found the duration of the tinnitus to be dependant upon the level of the inducing tone for the 1 minute condition ($F(5,20)=2.95, p<0.05$), but not for the 3 minute condition ($F(4,20)=0.66, p>0.05$), or the 5 minute condition ($F(3,15)=0.52, p>0.05$). On the other hand, two-way analyses of variance, using three durations (1, 3 and 5 minutes) and four levels of the inducing tone (80, 85, 90 and 95 dB SPL) found no significant relationship between the level of the inducing tone and the duration of the tinnitus ($F(3,15)=0.55, p>0.05$); duration of exposure to the inducing tone produced no significant effect ($F(2,10)=1.16, p>0.05$); and the interaction effect was not significant ($F(6,30)=0.63, p>0.05$).

The discrepancy between the one-way and two-way analyses of variance regarding the duration of the tinnitus is probably due to the exclusion of the 100 dB and 105 dB conditions in the latter statistical analysis. These conditions were not included, of course, because of the requirement that treatment factors be crossed to conduct a two-way analyses of variance. That is, all cells in the array need to be filled. The 100 dB and 105 dB conditions did not fulfil this criteria by not being presented for all exposure conditions. Presumably, then it is only the highest tone levels (100 and 105 dB SPL) that really lengthen the duration of the tinnitus.

PART 2: EFFECT OF FREQUENCY ON THE INDUCING TONE

This part of the experiment considered the effects of different frequencies of fixed intensity (90 dB SPL) and duration (3 minutes) to five subjects (7 ears). Two subjects completed all trials in both ears (Subjects 1 and 5), the rest completed all trials for one ear. It was decided to assign 90 dB for three minutes as the fixed intensity and duration, respectively, on the basis of the results given above. It seemed these conditions produced an easily distinguishable tinnitus pattern without causing the subject undue discomfort.

As in Part 1, the loudness of the induced tinnitus will be discussed separately from its duration.

(1) Loudness of the Induced Tinnitus

Table 4 gives the peak loudness of the tinnitus. Sensation levels range from -4.5 dB to 12.5 dB. The first thing to be noticed is that the levels of tinnitus for Ears 9 and 10 are frequently subthreshold. This curious effect is discussed below.

Looking at the peak loudness levels in Table 4 no obvious relationship between the loudness of the tinnitus and the frequency of the inducing tone is apparent.

FREQ.	Ear 1	Ear 2	Ear 6	Ear 7	Ear 8	Ear 9	Ear 10
500	6	6	8·5	11·5	3	-1	-0·5
1000	6	6	7	8	6	1	-1
2000	8·5	8	12	7·5	0	0	-3·5
3000	6	10	10·5	12·5	10	-4	-4·5
4000	4	6·5	10·5	12·5	11	1	-0·5

[values in dBSL]

Table 4: Peak loudness (maximum reached) of the white noise being matched in loudness to the contralateral tinnitus for each subject in each frequency. Loudness ranges from -4.5 dB to 12.5 dB SL. Subject 7 (Ear 10) reported tinnitus that was subthreshold while subjects 5 and 6 (Ears 8 and 9) reported no tinnitus in the 2000 Hz condition.

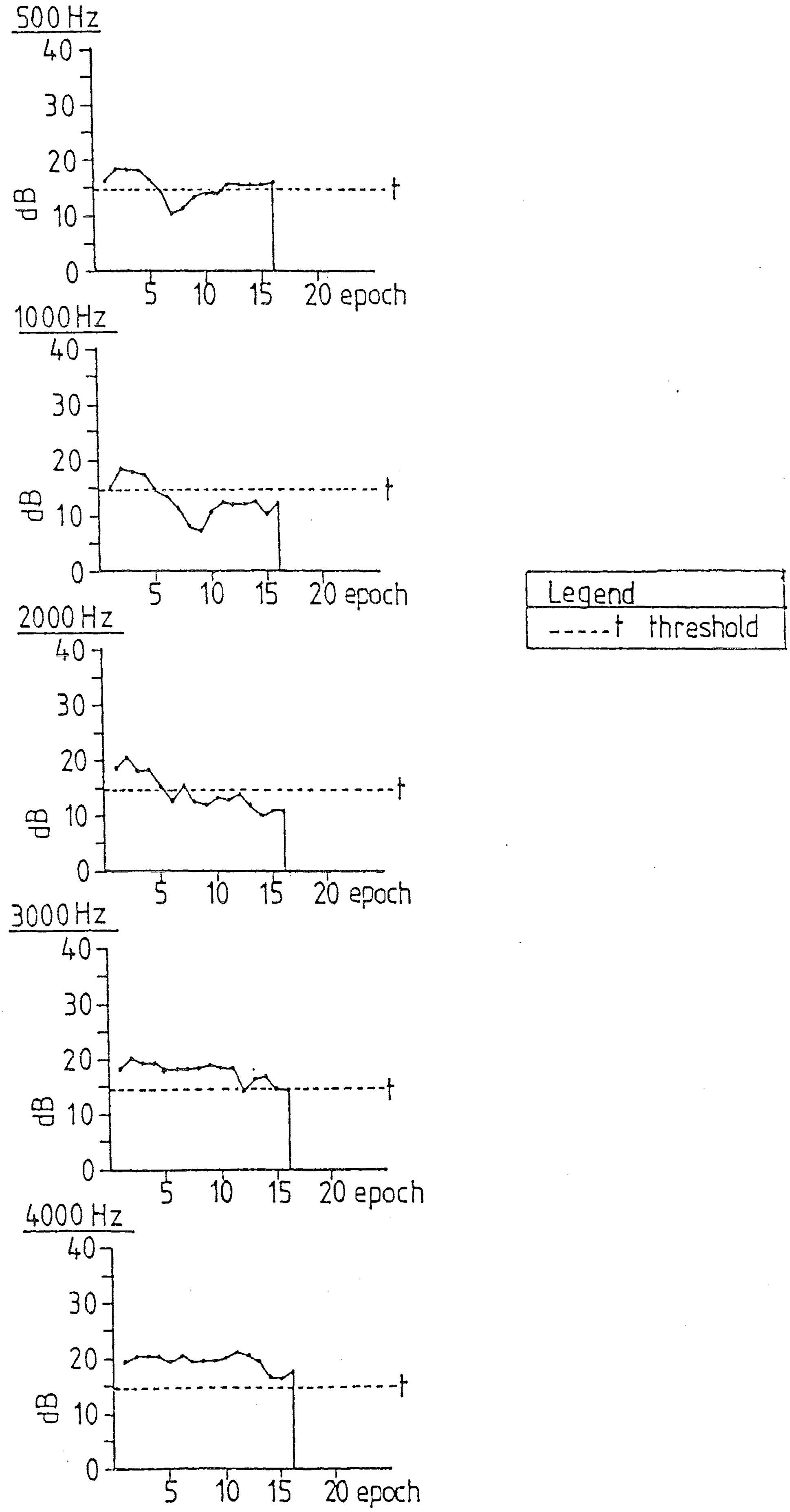
Figure 6 shows the loudness of the tinnitus averaged across all ears. For the individual data readers are referred to Appendix 2.

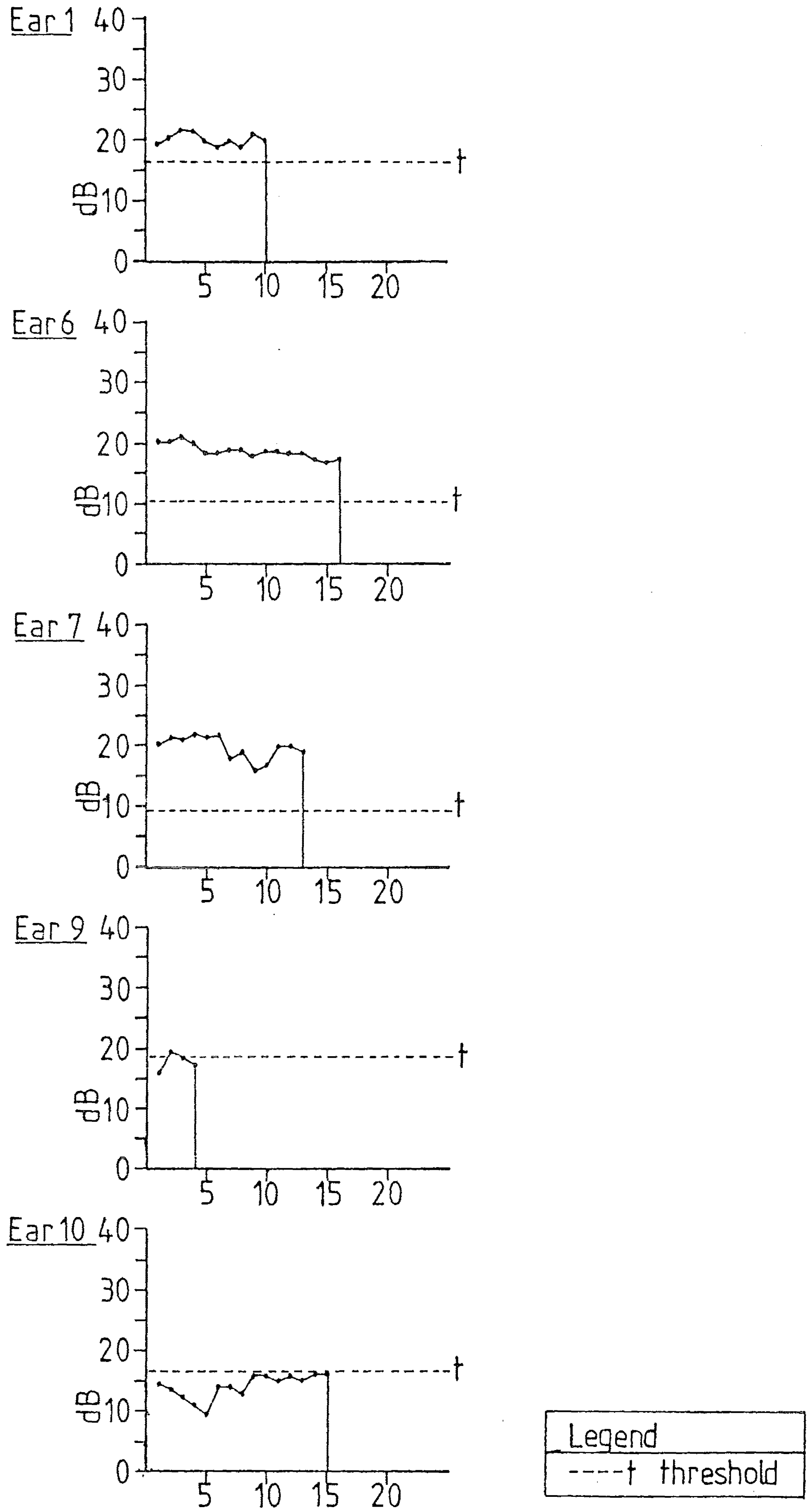
One-way analyses of variance found that the frequency of the inducing tone had no significant effect on the loudness of the tinnitus ($F(4,24)=0.66, p>0.05$). Thus it again appears that the loudness of the tinnitus is more dependant upon the qualities of the individual ears rather than upon the inducing tone.

Figure 7 illustrates the tinnitus from five subjects (5 ears) for the 4000 Hz condition. One of the first things to be noted is that the thresholds vary, as already noted for Figure 4. Tinnitus loudness appears to fluctuate around 19-20 dB SPL for Ears 1(3-4 dB SL), 6(8-9 dB SL) and 7(9-10 dB SL), while Ears 9(18-19 dB SPL) and 10(14-16 dB SPL) are predominantly subthreshold (-1 to 0 dB SL, and -4 to -2 dB SL, respectively). This substantial individual variation may have obscured smaller effects of frequency on the loudness of the tinnitus.

(2) Duration of the Induced Tinnitus

Table 5 shows the duration of the tinnitus for each condition. The tinnitus duration ranges from 0 to 233 seconds; 233 seconds was the maximum recordable. There does not appear to be any relationship between


500 Hz
1000 Hz
2000 Hz
3000 Hz
4000 Hz
dB
0 10 20 30 40
5 10 15 20 epoch
t
Legend
-----t threshold


Ear 1
Ear 6
Ear 7
Ear 9
Ear 10
dB
0
10
20
30
40
5
10
15
20
Legend
----† threshold

FREQ	Ear 1	Ear 2	Ear 6	Ear 7	Ear 8	Ear 9	Ear10
500	79	63	90	57•5	53•5	61•6	231•5
1000	80	63	81•5	126•3	75•5	55	233
2000	66•5	94	79	114•3	0	0	233
3000	69	126•6	162•6	148•3	96•5	53•6	137•6
4000	109	116	233	110	151•5	55	161•5

(values in sec.)

Table 5 Duration of the tinnitus (seconds) for each subject in each frequency. Durations range from 0 to 233 seconds. Note the anomalous behaviour of Subject 7 (Ear 10); as the frequency of the inducing tone increases the duration of the induced tinnitus decreases.

the frequency of the inducing tone and the duration of the tinnitus. Indeed, this was borne out under statistical analysis ($F(4,24)=1.63, p<0.05$).

Note the anomolous behaviour of Ear 10, which is difficult to explain. This subject produced tinnitus recordings of maximum length for the lower frequencies (500, 1000, and 2000 Hz) and then at the higher frequencies (3000 and 4000 Hz) produced tinnitus of shorter duration. According to the initial hearing test this subject proved to be particularly sensitive to these higher frequencies. Perhaps it was the sensitivity to these higher frequencies which was responsible for the shorter durations.

An interesting point, and again difficult to explain, is that two subjects, 5 and 6 (Ears 8 and 9) reported not hearing any tinnitus in the 2000 Hz condition, even after four trials. Tinnitus of considerable duration (114.3 seconds) was recorded from Subject 5 (Ear 7), compounding the difficulty. Both subjects fulfilled the selection criteria for this frequency, by having hearing levels between -10 dB and +20 dB.

CHAPTER V

DISCUSSION

Previous studies concerned with noise induced tinnitus employed inducing stimuli of much greater magnitude than used in the present study. Loeb and Smith (1967) used stimuli with an initial exposure of 90 dB SPL for five minutes, with each subject being run repeatedly with progressively increased levels of exposure, until a temporary threshold as great as 40 dB was established, or until the inducing stimuli reached 120 dB SPL. Atherley et al (1968) used an inducing stimulus level of 110 dB SPL for a period of five minutes.

The inducing stimuli used in this study were varied, ranging from 80 dB SPL to 105 dB SPL, in five decibel increments. Length of exposure to the inducing stimuli was also varied; 1, 3 and 5 minute durations were employed.

Another important difference between this and earlier studies relates to data collection. Loeb and Smith (1967) and Atherley et al (1968) were interested in matching the induced tinnitus for pitch and loudness using the contralateral ear. The present study attempted to investigate the time course of the loudness of the tinnitus. No attempt was made to record the pitch of the tinnitus; Hazell (1981) has shown that tinnitus is a complex sound, and thus it would have required longer than the tinnitus lasted to measure the pitches accurately. Moreover the sound of the tinnitus in this experiment was not reported to be tonal.

Part 1 of the present study investigated the effects of different intensity levels, for different exposure conditions, on the loudness and the duration of the tinnitus. Generally, as the level of the inducing tone was increased, the loudness of the tinnitus also increased (refer to Figure 3). Tinnitus loudness was found to be significantly related to the level of the inducing tone for the one minute conditions, but not the three or five minute conditions.

The loudness of the tinnitus appeared to fluctuate about 4 dB SL in the 80, 85 and 90 dB conditions, while for the 95, 100 and 105 dB conditions the tinnitus reached levels in the vicinity of 10-15 dB SL. Associated with the increase in loudness, there was also an increase in the build up period, that is, as the level of the inducing tone exceeded 95 dB SPL, there was an increased latency period before the plateau level of tinnitus was reached. (See Figure 3).

The duration of the induced tinnitus exhibited no relationship to the duration of the inducing stimuli.

A significant relationship was observed between the duration of the tinnitus and the duration of the inducing stimuli for the one minute condition but not the three or five minute conditions. Consequently, the duration of the tinnitus would appear more dependent upon the characteristics of the individual ear rather than upon the characteristics of the inducing stimuli.

The second part of the study was concerned with the effects of the frequency of the inducing tone on the loudness and duration of the tinnitus. Neither loudness nor duration was found to be significantly related to the frequency of the inducing tone.

Atherley et al (1968) report loudness of induced tinnitus compatible with the results reported in this study, for three frequencies in common; 2000, 3000 and 4000 Hz. For the 2000 Hz condition they obtained a loudness of 11.0 dB SL compared with 4.6 dB SL obtained here; for the 3000 Hz condition 5.0 dB SL compared with 5.8 dB SL obtained here, and for the 4000 Hz condition 8.0 dB SL compared with 6.4 dB SL obtained here. It must be remembered, despite the similarity of the results, that there was a substantial difference between the level of the inducing stimuli of the earlier study (110 dB SPL for 5 minutes) and that of the present study (90 dB SPL for 3 minutes).

Atherley et al (1968) claimed that 89 per cent of their subjects developed tinnitus as a consequence of being exposed to stimuli of 110 dB SPL for 5 minutes.

All subjects in the present study, except subjects 5 and 6 (Ears 8 and 9) in the 2000 Hz condition in Part 2, reported some form of after effect - even in the 80 dB condition for 1 minute. One might expect, on this basis, that an inducing tone of 110 dB SPL for 5 minutes all subjects should have developed tinnitus - if not some form of hearing loss.

The early studies reported that the frequency of the induced tinnitus increases with stimulus frequency. Although this was outside the realms of the present study, verbal reports from one subject, indicated that the only noticeable effect was in the 500 Hz condition. The tinnitus induced in this condition was reported as being a low rumbling sound, although still of the rushing type. Hirsh and Ward (1951) reported a similar phenomenon - "after stimulation by a 500-cycle tone, an unusually loud roaring noise is heard in the background, but the noise seems to get weaker and eventually die out at about 70 or 80 seconds, just as the threshold is beginning to rise again." (p135). Their inducing stimulus comprised 120 dB SPL for 3 minutes, while the present study used 90 dB SPL for 3 minutes. This was the only report indicating a shift in the pitch of the induced tinnitus as a consequence of the frequency of the inducing tone.

The subjects here may not have paid as much attention to the pitch of the tinnitus as they did to the loudness. Subjects were instructed to match only the loudness of their tinnitus with the contralaterally presented white noise.

Despite the large differences in level of inducing stimuli used in the Hirsh and Ward (1951) study and the present study (120 dB SPL for 3 minutes, compared with 90 dB SPL for 3 minutes) the average duration of the induced tinnitus does not differ markedly. Hirsh and Ward report the tinnitus induced in their study decayed after 70-80 seconds, while the tinnitus induced in the second part of the present study lasted 80-85 seconds, on average.

When looking at the individual results from both experiments (Appendices 1 and 2), the reader will notice considerable differences within and between subjects. The fact that these differences occur within the same subject suggests the disparities are variations in the tinnitus rather than performances on the dichotic loudness matching task. This, in turn, suggests that the induced tinnitus behaved in a similar manner to its pathological counterpart. The possibility of pathological tinnitus varying from day to day has been proposed previously (Penner, 1983 b). Since some of the differences occurred within the same subject, and indeed within the same ear on different days, it seems probable that the induced tinnitus varied in a similar vein to the pathological form.

The difference between ears of different subjects is more easily assigned to individual subjects responding differently to instructions, and thus adopting different criteria when monitoring their tinnitus.

The reader will notice, when looking at the graphs in the body of this manuscript (eg Figures 4, 6 and 7) and in the appendices (Ears 9 and 10: Appendix 2) that some subthreshold points are plotted. These are included because it was assumed that if subjects reported hearing tinnitus at these levels then it must have been present. It will also be noticed that subjects 6 and 7 (Ears 9 and 10) report tinnitus which is entirely subthreshold. The recordings were further substantiated by verbal reports indicating these subjects were hearing an after-effect similar to that of tinnitus. Explanations which may account for these subthreshold data include: (1) On the days of the experimental trials the subject's threshold may have been lower than when the threshold trials were administered; (2) Temporary Sensitization (Hughes and Rosenblith (1957)). It has been shown that when a stimulus is intense, initial fatigue is followed by sensitization and then secondary fatigue. The sensitization effect lessens when the intensity increases above the level that gives the maximal effect. This may occur at higher intensities because fatigue increases faster than sensitization (Hughes, 1954); (3) The two subjects, 6 and 7 (Ears 9 and 10) may have adopted different criteria for establishing their thresholds, or possibly matching their tinnitus.

Several subjects reported that while being exposed to the inducing tone, a temporary rushing noise built up in their contralateral ear, at the higher intensities (95, 100 and 105 dB SPL). This may be attributed to the hair cells, in the contralateral ear being stimulated as a result of bone conduction, via the skull (Lutman, 1983). The contralateral tinnitus would presumably have affected the dichotic loudness matching task. Subjects would have had difficulty distinguishing between the white noise being presented to the non-stimulated ear (at low levels) and the contralateral tinnitus already present.

The dichotic loudness matching task provides a useful measure of the tinnitus loudness, but is fraught with procedural problems. In the case of pathological tinnitus, loudness matching involves presenting a sound that represents the best match possible to the quality and pitch of the tinnitus. However, quality, pitch and loudness judgements are interdependent. For example, the best pitch match can not be achieved until the loudness is known. This problem was not encountered here since the matching task was only interested in the loudness of the tinnitus. When conducting a loudness matching task it is important to ensure an ascending series is employed. If a descending series is employed then residual inhibition may result.

The present study assumes that the level of white noise being dichotically matched, in loudness, represents the loudness of the induced tinnitus in the contralateral ear. This seems a justified assumption since the subject is matching two similar stimuli; - white noise and rushing noise tinnitus; as opposed to cross-modal matching (eg matching rushing noise tinnitus to a tonal comparison). In addition the matching of white noise to the induced tinnitus is a simultaneous process rather than a delayed presentation.

A point was made, early in the study, by one of the subjects, that the dichotic loudness matching task was made somewhat difficult because of the differing qualities of the white noise and the induced tinnitus. This subject reported the tinnitus sounded higher in pitch than did the white noise, indicating that the white noise produced a different spectrum of noise than did the induced tinnitus. This suggests that the inducing tone may have stimulated the area of the basilar membrane associated with 1000 Hz, while the white noise, being composed of various frequencies, stimulated a wider area.

The issue of loudness of the induced tinnitus is important in how it relates to the reported loudness of the pathological tinnitus. The data from the present study agrees with Penner (1983a)and Reed (1960), who report the loudness of tinnitus as typically under 20 dB SL, with a few people matching it in loudness to levels over 20 dB SL. It will be remembered that 67 per cent of the induced tinnitus, in Part 1, was below 10 dB SL; 30.5 per cent between 10 and 20 dB SL; and 2.5 per cent above 20 dB SL. Thus the tinnitus induced in the present study appears to behave in a similar manner to that of its pathological cousin.

Verbal reports from the subjects, in the present study seem to conflict with those of earlier studies. Loeb and Smith (1967) and Atherley et al (1968) reported that tinnitus induced in their subjects was tonal. Subjects in the present study reported a rushing noise tinnitus, with an occasional tonal component. Instead of a gradual decline in loudness, subjects reported their tinnitus ceasing abruptly.

CHAPTER VI

CONCLUSION

The results obtained in this study suggest that the induced tinnitus is more dependent upon the characteristics of the individual ear than upon the inducing tone.

The level of the inducing tone was found to produce significant effects on the loudness and duration of the induced tinnitus for the 1 minute condition but not for the 3 or 5 minute conditions.

The reported loudness of the induced tinnitus ranged from -4.5 dB SL to 24.5 dB SL, with an average of 7.8 dB SL.

All subjects reported a rushing noise tinnitus, thus supporting the earlier studies of Ewing and Littler (1935) and Hirsh and Ward (1952), but not Loeb and Smith (1967) nor Atherley et al (1968) who reported a tonal tinnitus resulting from both tonal and broad-band inducing stimuli.

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My typist, Mrs E. Jonas, for her patience in having had numerous pages to type and then alter at a later date.

Finally, I would like to thank my subjects for their support, particularly since they spent a considerable amount of time in a small sound-proof room listening to tones of various intensities and frequencies.

To you all, thank you very much.

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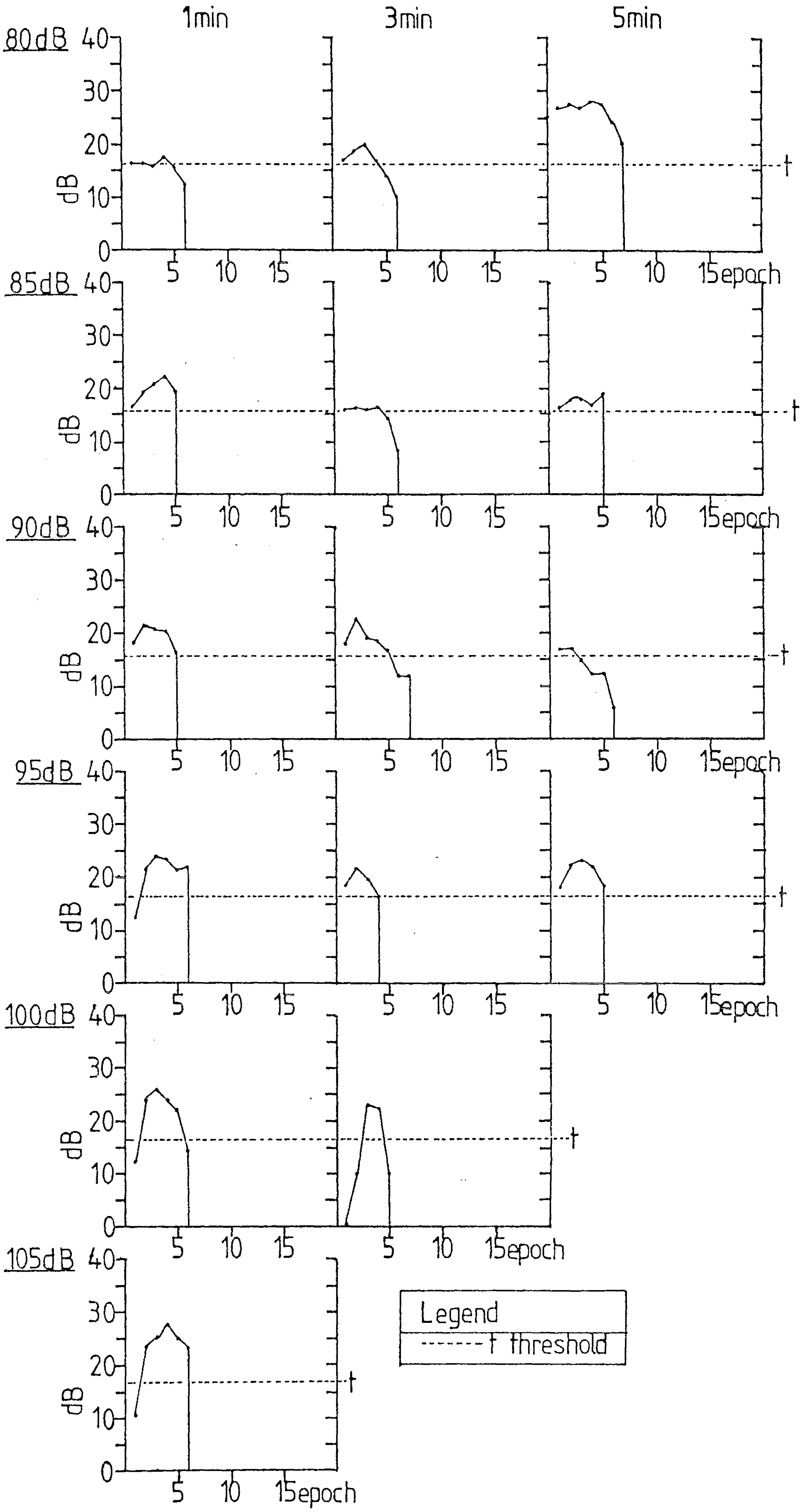
APPENDIX 1

Individual Results from Part One

Subject 1	-	Ear 1
	-	" 2
Subject 2	-	" 3
	-	" 4
Subject 3	-	" 5
Subject 4	-	" 6

The following graphs show the level of white noise (dB SPL) matched in loudness to the contralateral tinnitus as a function of time (1 epoch = 15 seconds) following 1000 Hz tonal stimulation. Separate panels are shown for three durations of the inducing tone (1, 3 and 5 minutes) and six levels of the inducing tone (80, 85, 90, 95, 100 and 105 dB SPL) - except Subject 4 (Ear 6) where no 105 dB conditions were employed. The average white noise threshold is plotted in each panel.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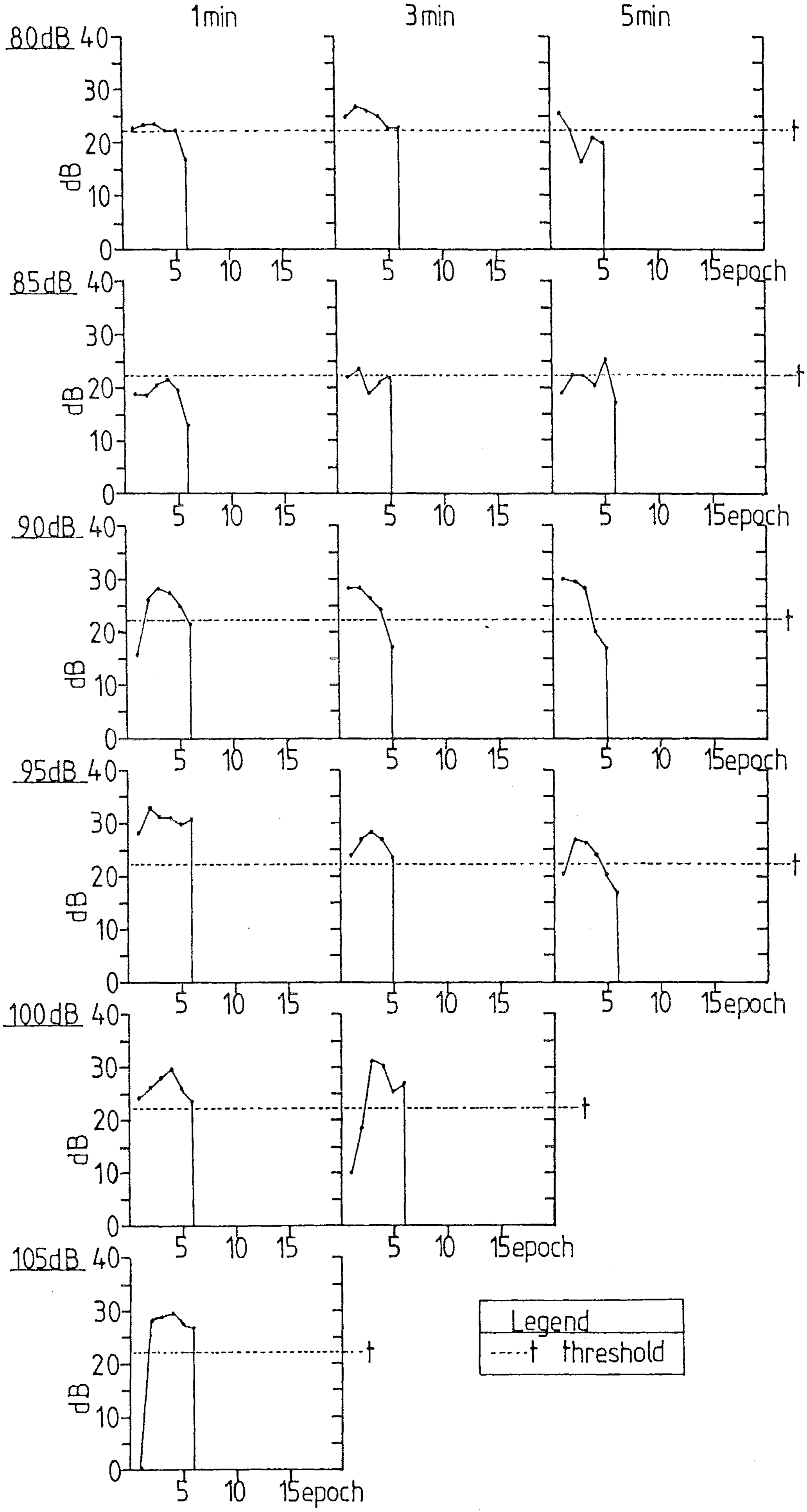
EAR 1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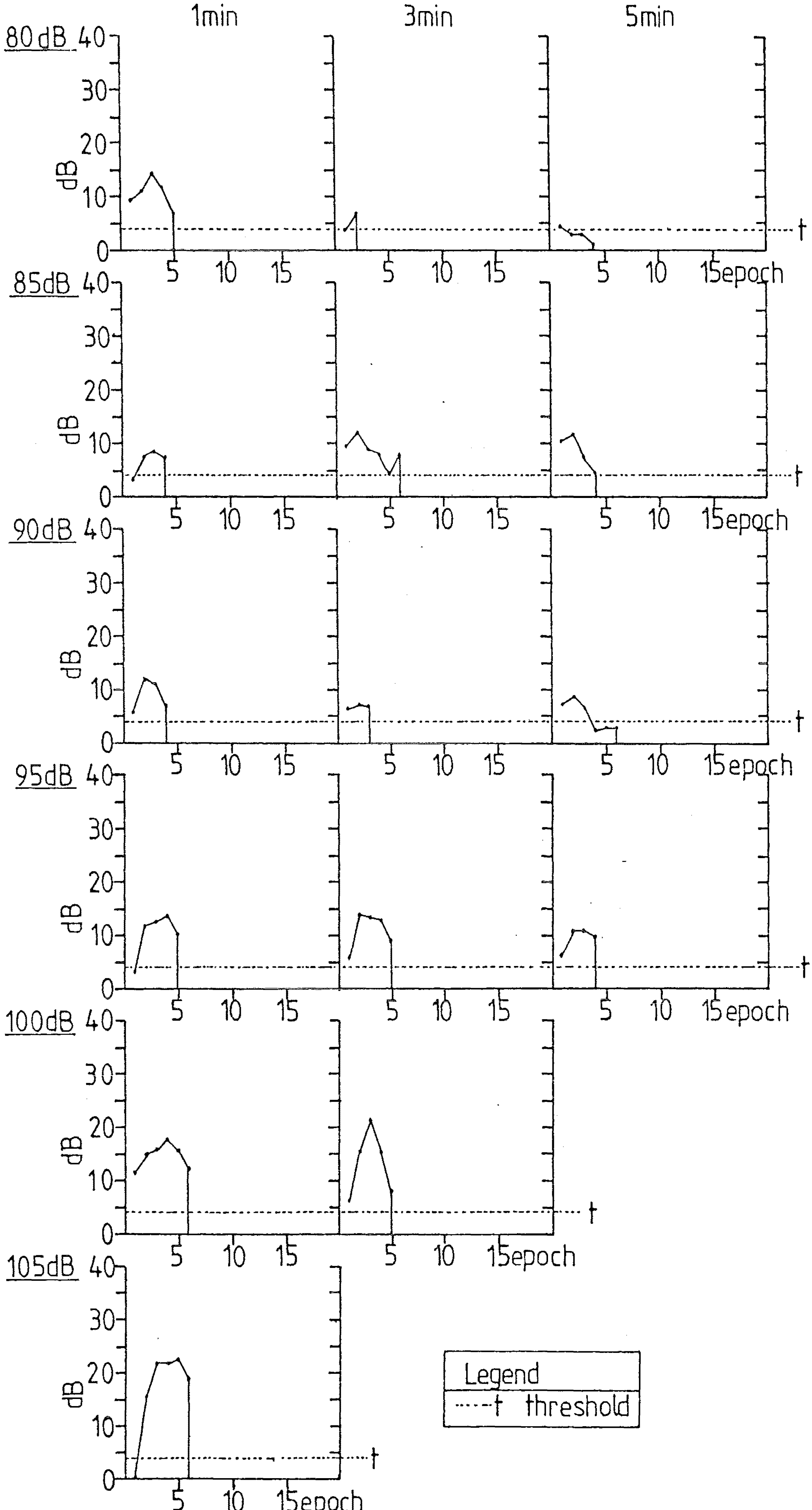
EAR 2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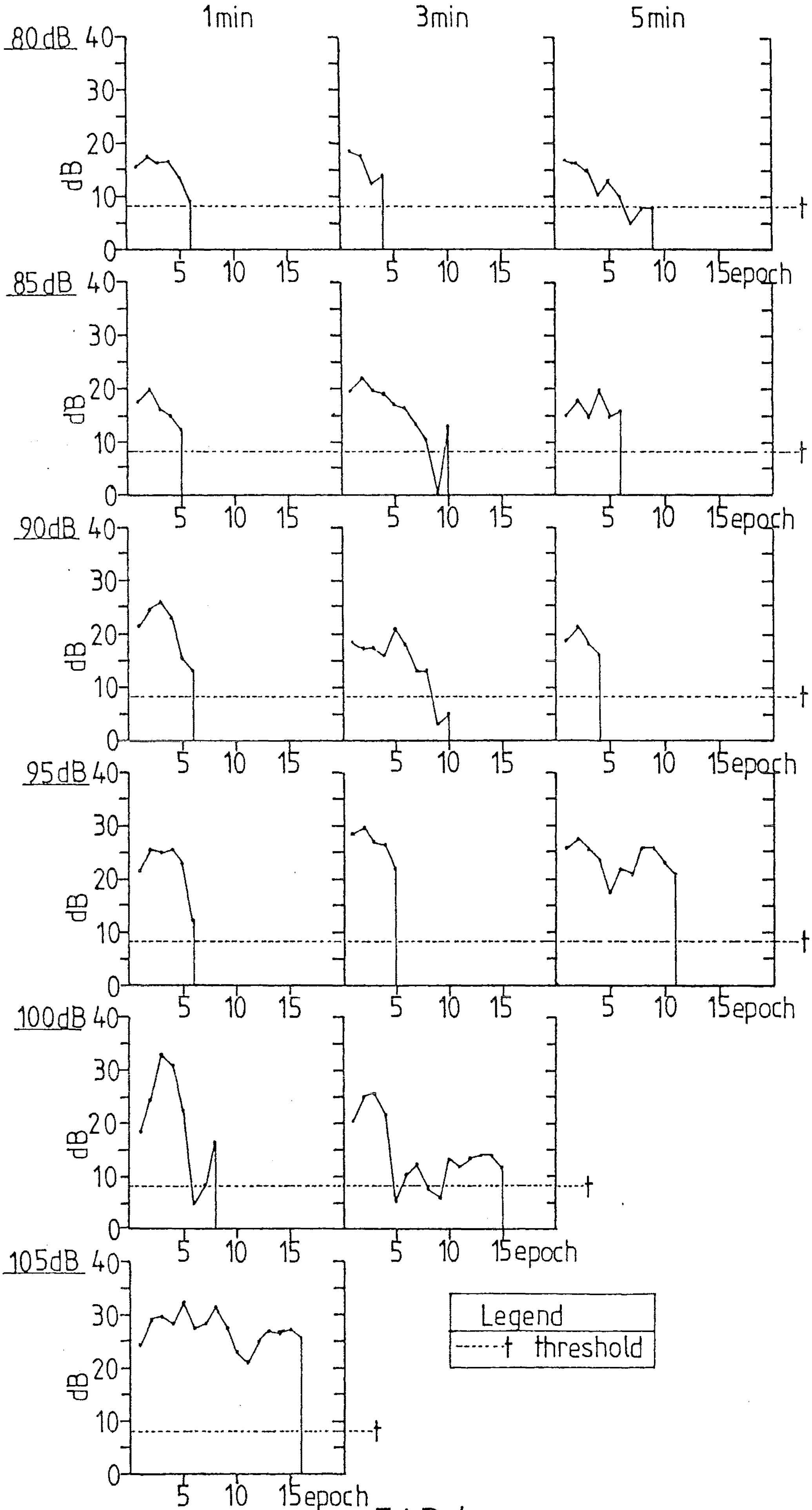
EAR 3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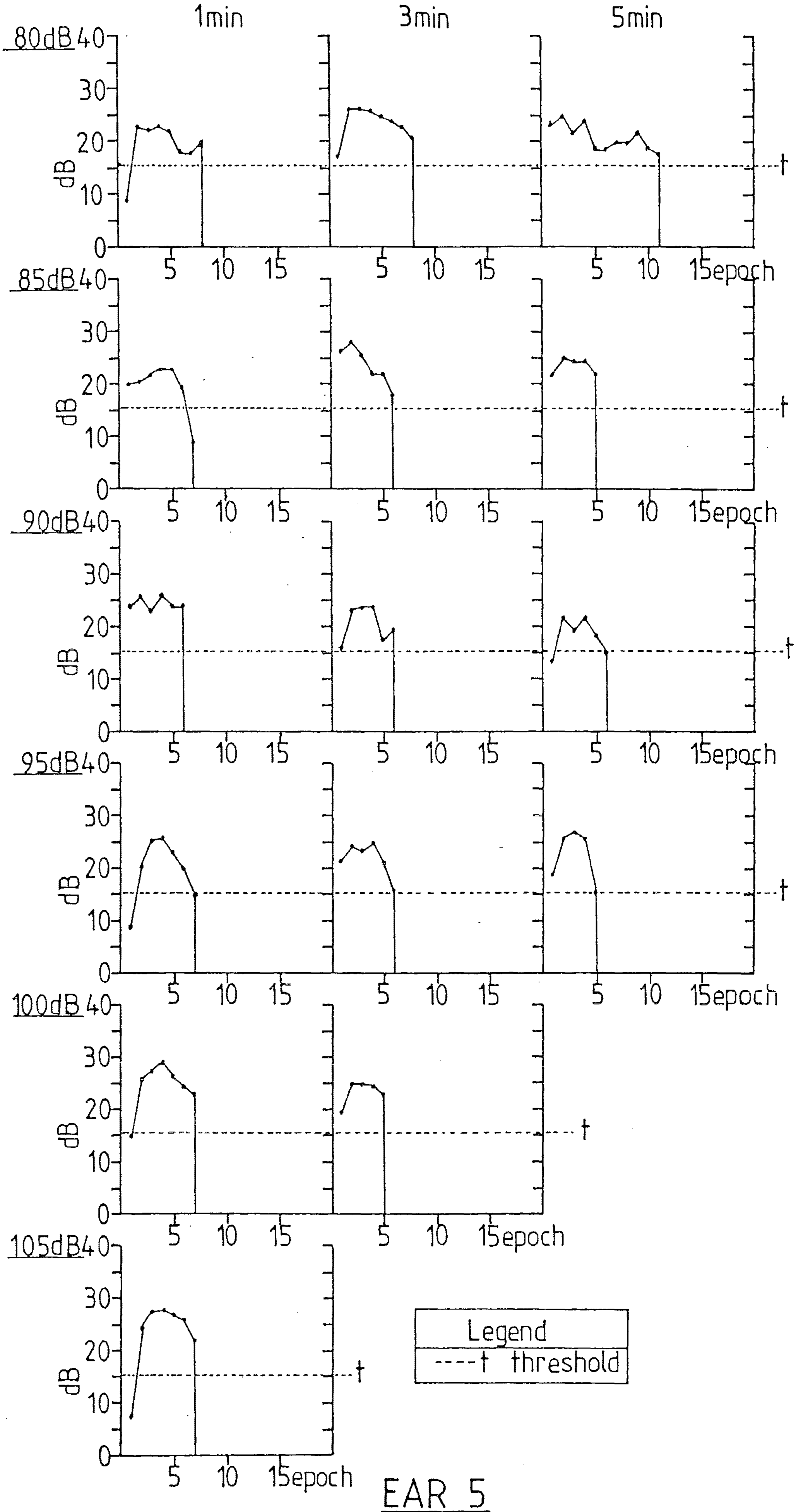
------† threshold

EAR 4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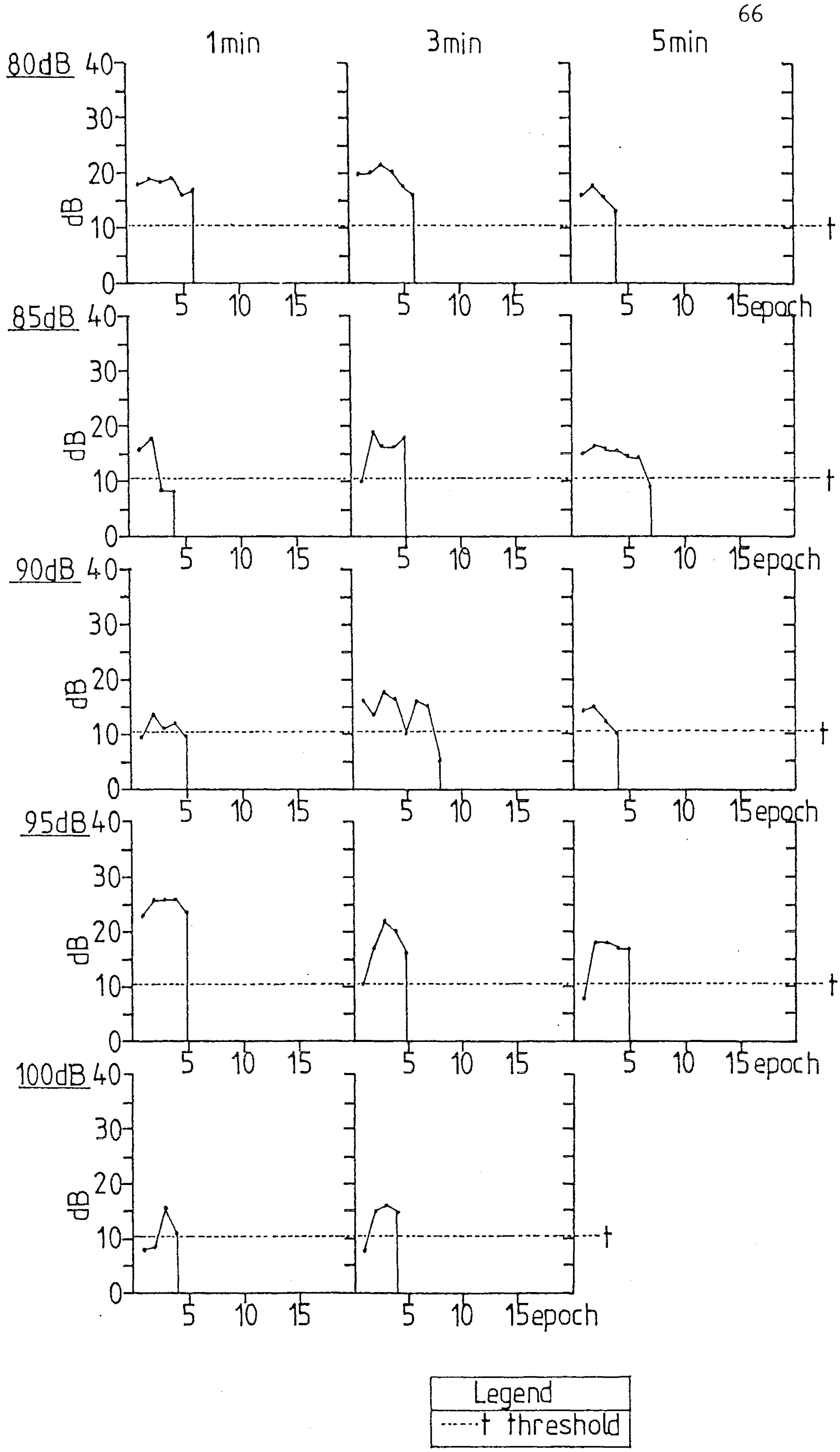
EAR 5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0
10
20
30
40
5
10
15
epoch
Legend
t threshold

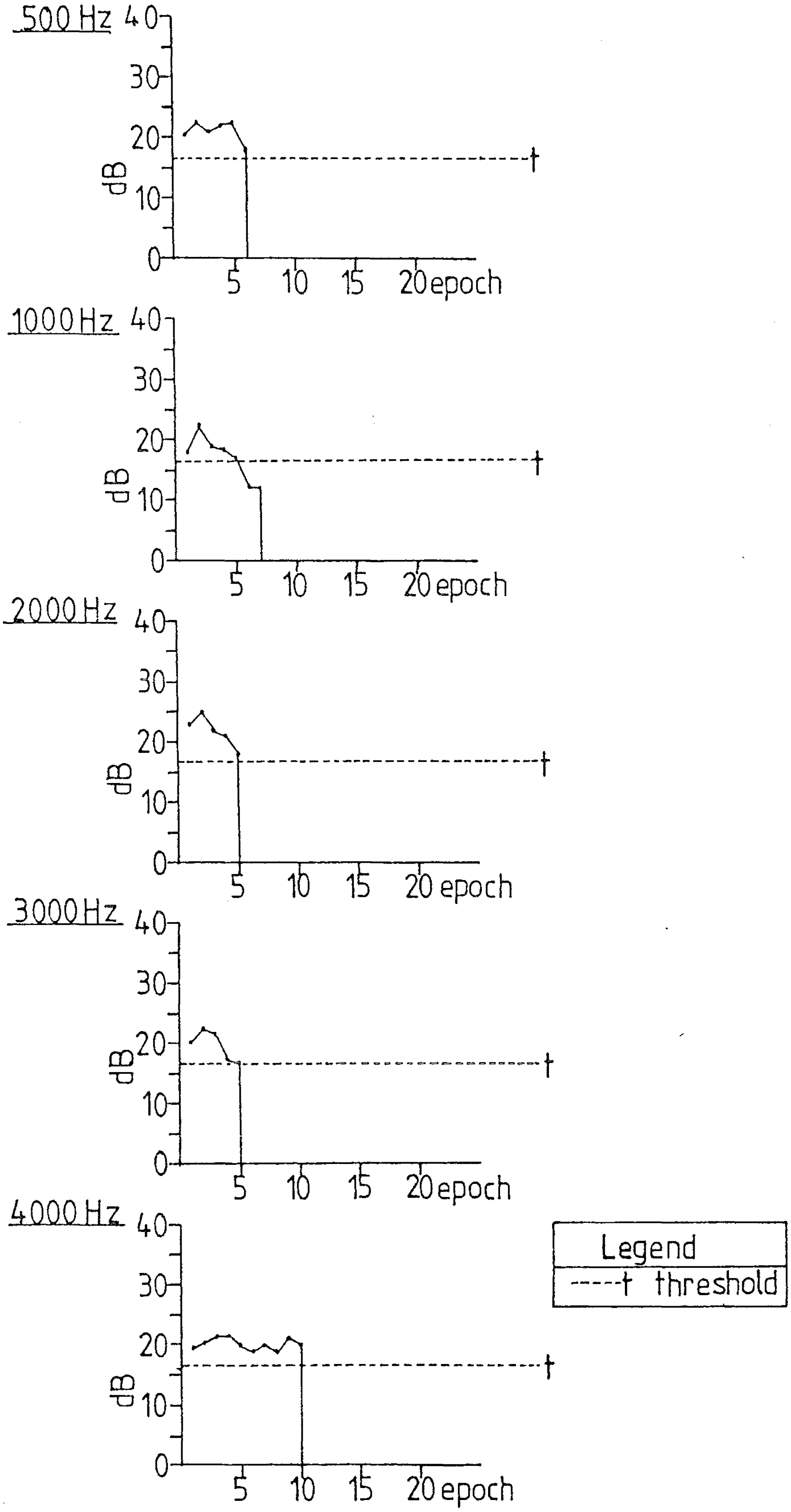
EAR 6

APPENDIX 2

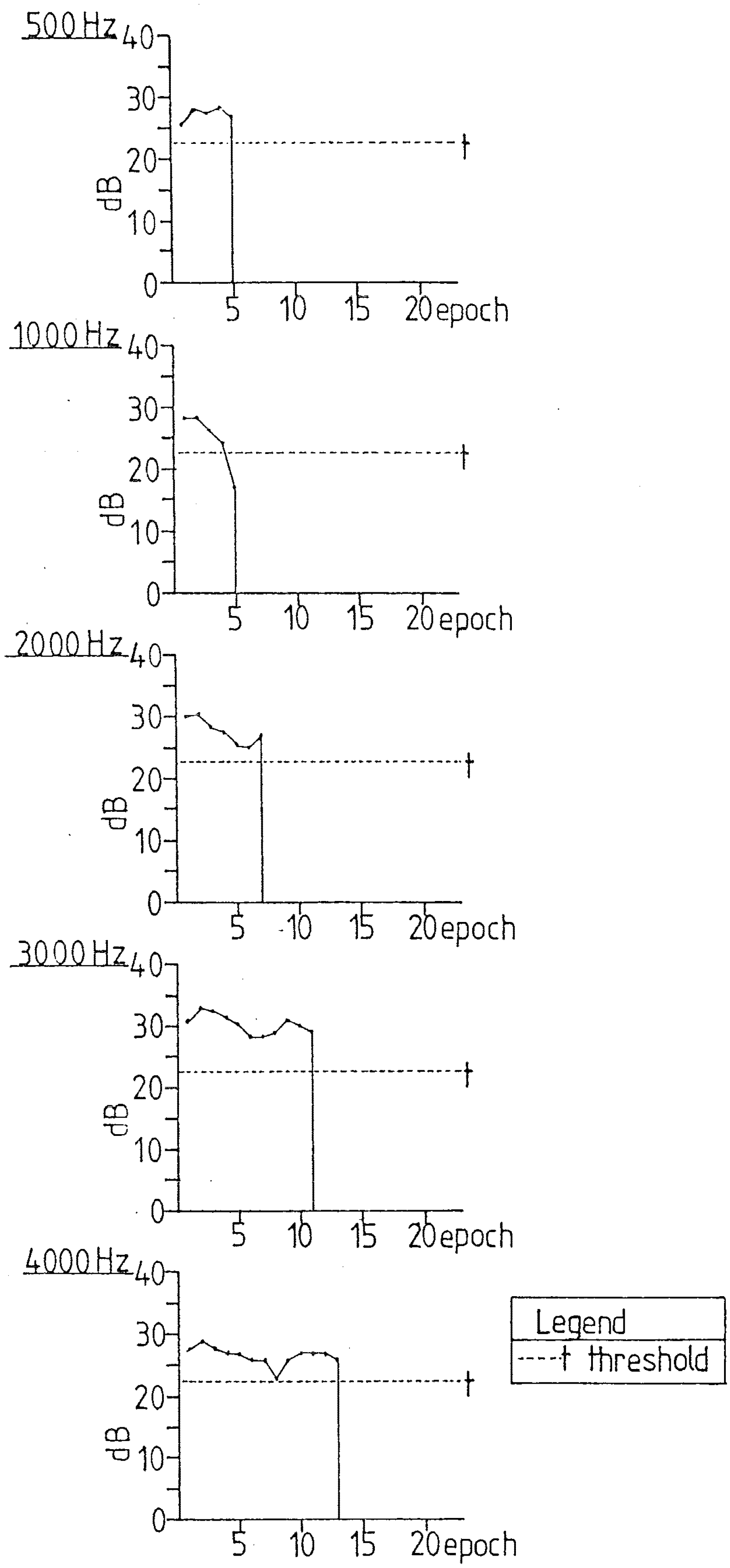
Individual Results from Part Two

Subject 1	-	Ear 1
	-	" 2
Subject 4	-	" 6
Subject 5	-	" 7
	-	" 8
Subject 6	-	" 9
Subject 7	-	" 10

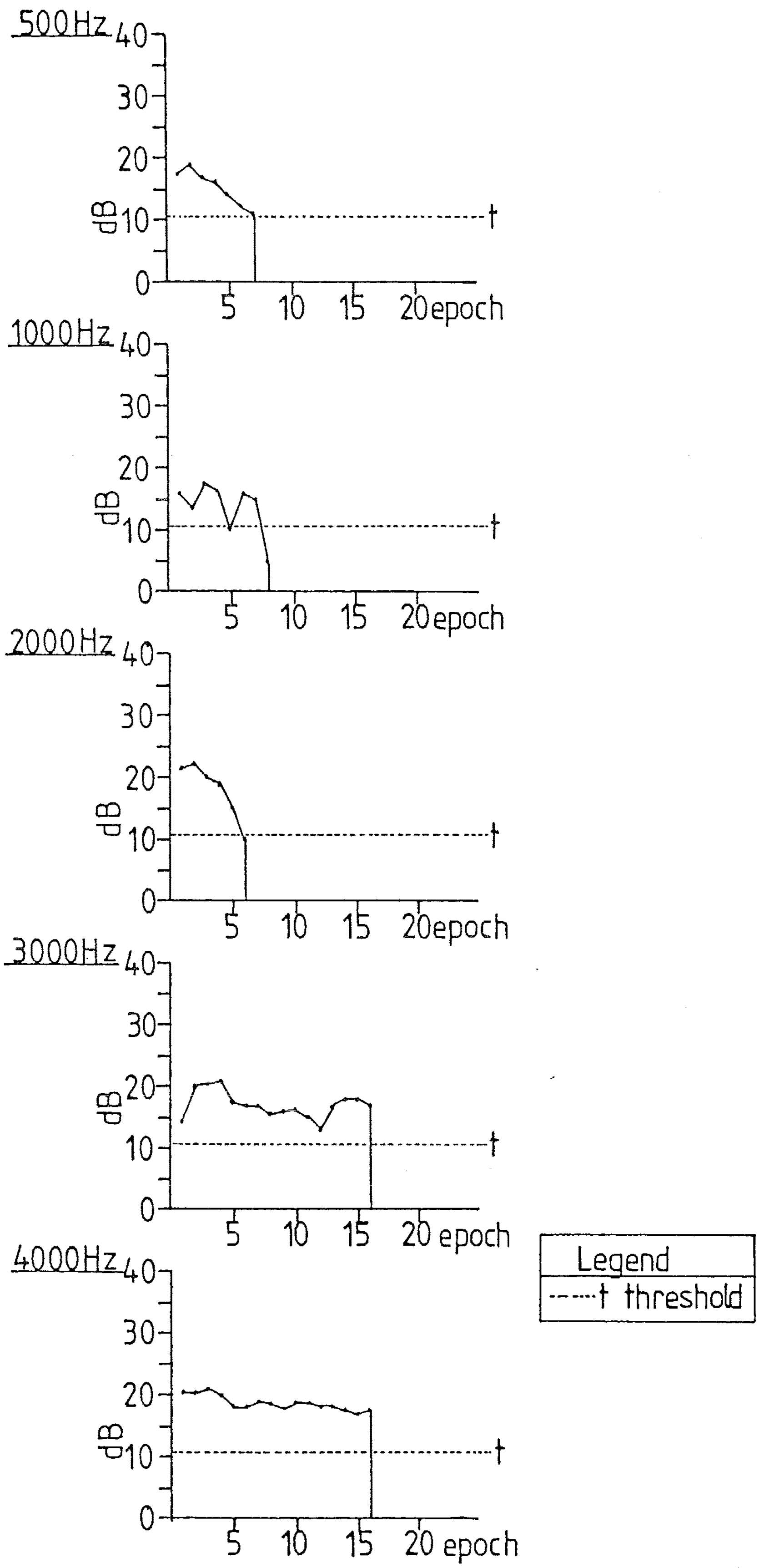
The following graphs show the level of white noise (dB SPL) matched in loudness to the contralateral tinnitus as a function of time (1 epoch = 15 seconds) following stimulation by five tonal inducing stimuli, (500, 1000, 2000, 3000, and 4000 Hz). The level and duration of the inducing tone are fixed at 90 dB SPL and 3 minutes, respectively. The average white noise threshold is plotted for each frequency.


500 Hz
1000 Hz
2000 Hz
3000 Hz
4000 Hz
dB
0
10
20
30
40
5
10
15
20 epoch
Legend
----† threshold

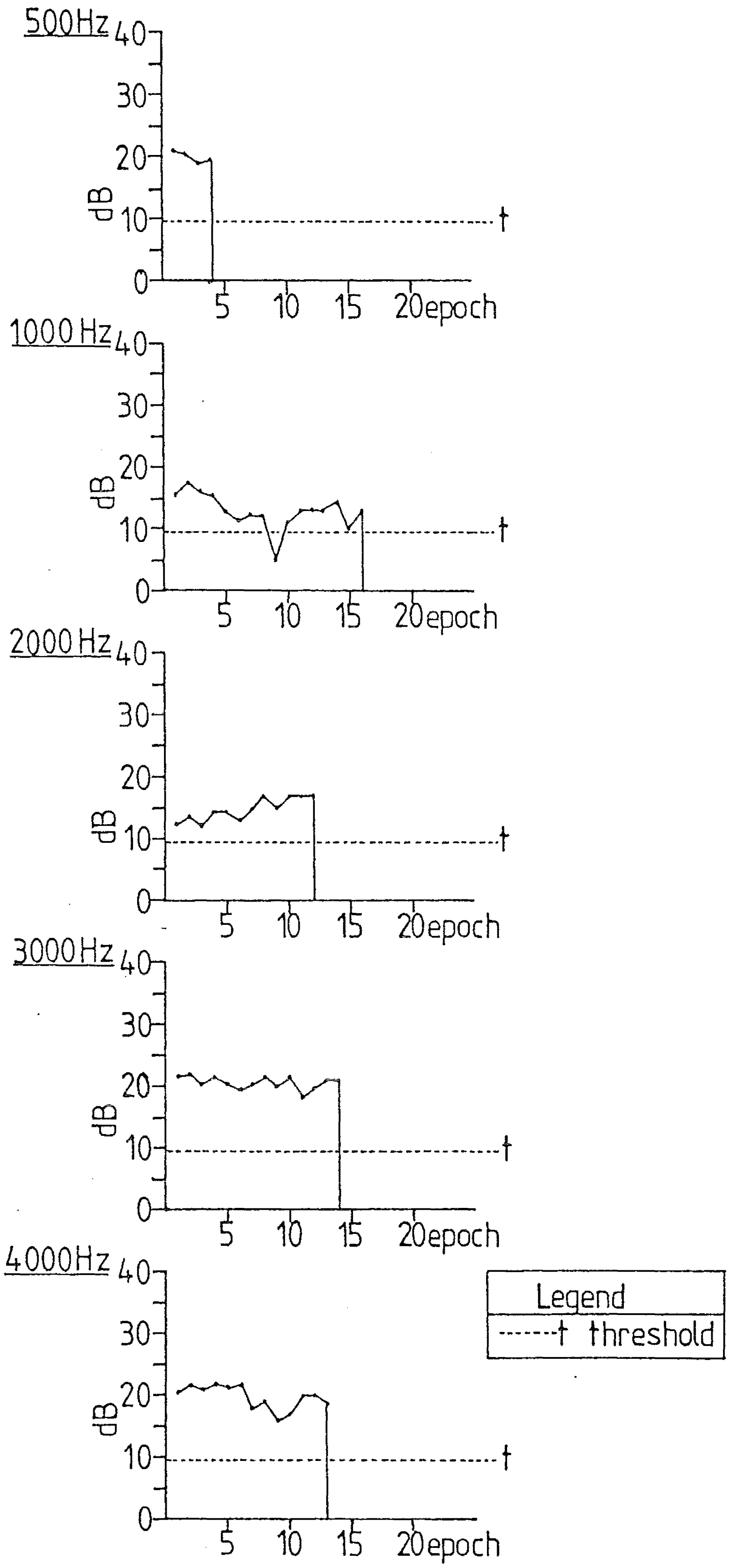
EAR 1


500 Hz
1000 Hz
2000 Hz
3000 Hz
4000 Hz
dB
0
10
20
30
40
5
10
15
20
epoch
Legend
threshold

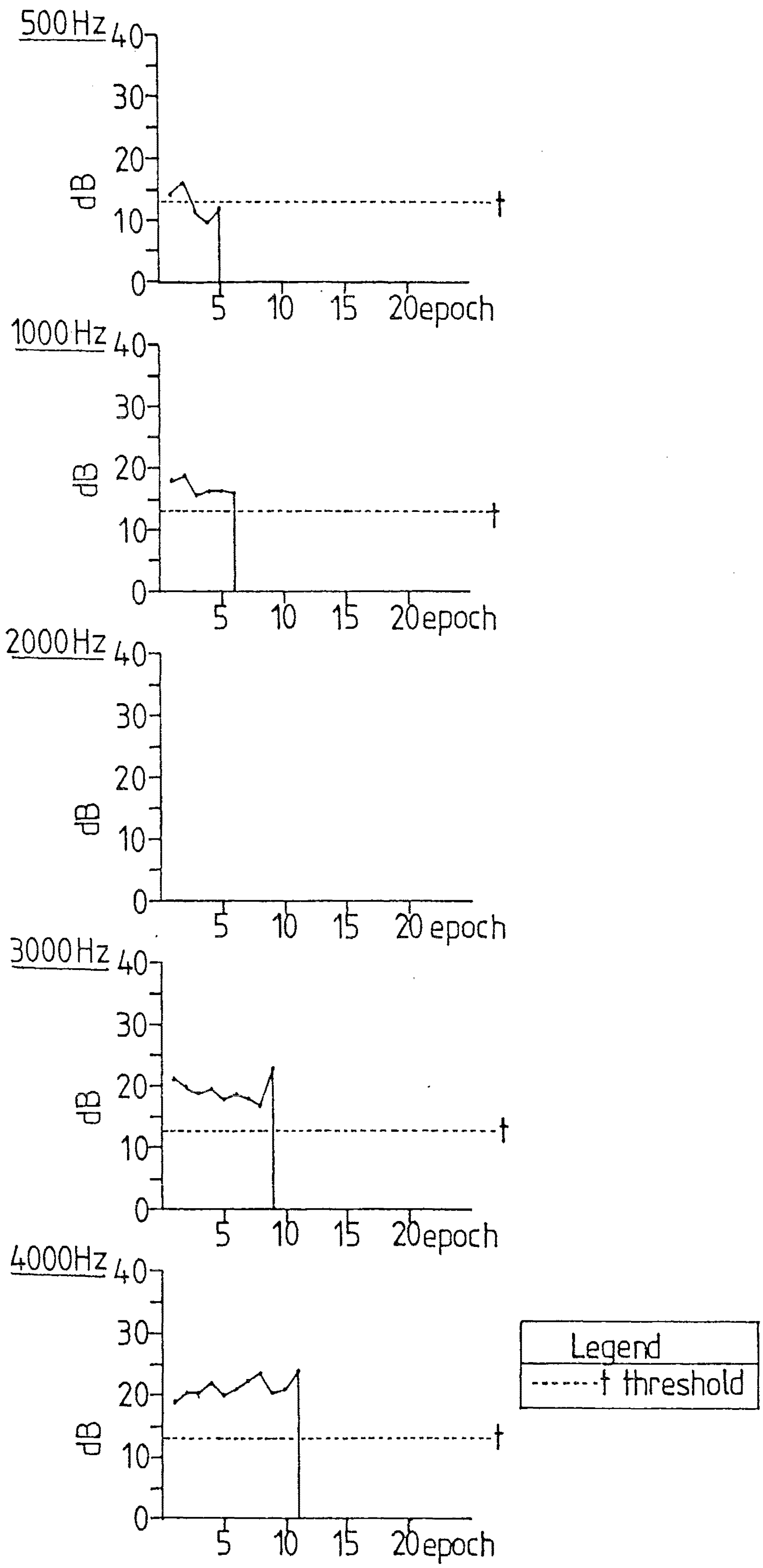
EAR 2


500Hz
1000Hz
2000Hz
3000Hz
4000Hz
40
30
20
10
0
dB
5
10
15
20
epoch
t
Legend
t threshold

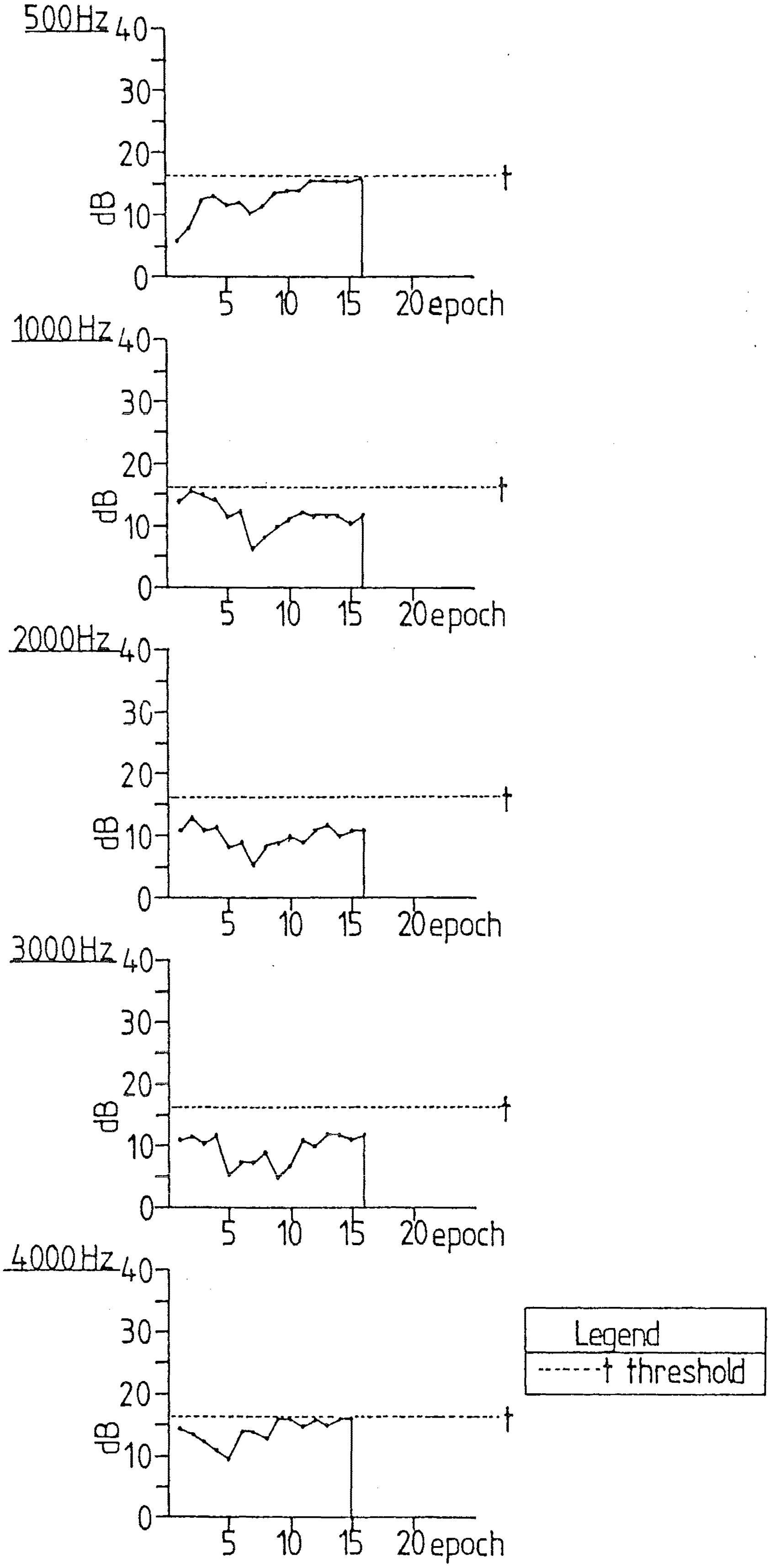
EAR 6


500Hz
1000 Hz
2000 Hz
3000 Hz
4000Hz
dB
40
30
20
10
0
5
10
15
20epoch
Legend
------† threshold

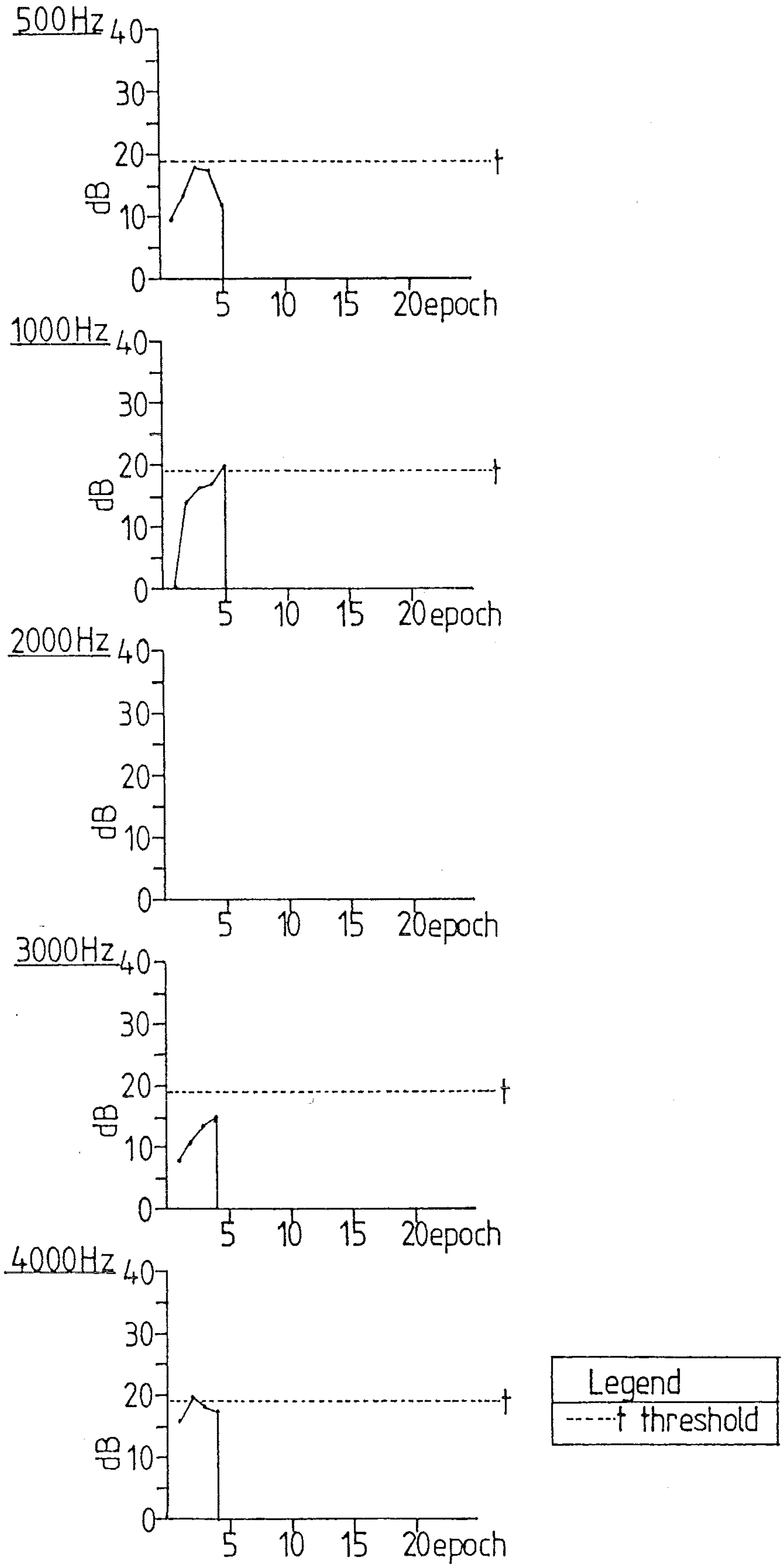
EAR 7


500 Hz
1000 Hz
2000 Hz
3000 Hz
4000 Hz
dB
40
30
20
10
0
5
10
15
20 epoch
Legend
------† threshold

EAR 8


500Hz
1000Hz
2000Hz
3000Hz
4000Hz
40
30
20
10
0
dB
5
10
15
20 epoch
Legend
------† threshold

EAR 10


500Hz
1000Hz
2000Hz
3000Hz
4000Hz
dB
0
10
20
30
40
5
10
15
20epoch
Legend
----† threshold

EAR 9